DM Supplement Overhead Sign Illumination (Lighting)

850 Traffic Control Signals

850.01 General

Traffic control signals are power-operated traffic control devices that warn or direct motorists to take some specific action. More specifically, signals are used to control the assignment of right of way at locations where conflicts exist or where passive devices, such as signs and markings, do not provide the necessary flexibility of control to move traffic in a safe and efficient manner.

850.02 References

The following references are used in the design, construction, and operation of traffic control signals installed on state highways. The Revised Codes of Washington (RCWs) noted below are specific state laws concerning traffic control signals and conformance to these statutes is required.

RCW 35.77, "Streets-Planning, establishment, construction, and maintenance."

RCW 46.61.085, "Traffic control signals or devices upon city streets forming part of state highways—Approval by department of transportation."

RCW 47.24.020 (6) and (13), "Jurisdiction, control."

RCW 47.36.020, "Traffic control signals."

RCW 47.36.060, "Traffic devices on county roads and city streets."

Washington Administrative Code (WAC) 468-18-040, "Design standards for rearranged county roads, frontage roads, access roads, intersections, ramps and crossings."

Directive D 55-03, "Responsibility for Traffic Control Devices, Pavement Widening, and Channelization at Existing Intersections and Two-Way Left Turn Lanes in Cities"

Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), USDOT, Washington DC, 1988, including the *Washington State Modifications to the MUTCD*, M 24-01, WSDOT, 1996

Plans Preparation Manual, M 22-31, WSDOT

Standard Plans for Road, Bridge, and Municipal Construction (Standard Plans), M 21-01, WSDOT

850.03 Definitions

The various types of traffic control signals are defined below. Hazard identification beacons and ramp meter signals are energized only at specific times. All other signals remain in operation at all times.

conventional traffic signal A permanent or temporary installation providing alternating right of way assignments for conflicting traffic movements. At least two identical displays are required for the predominant movement on each approach.

emergency vehicle signal A special adaptation of a conventional traffic signal installed to allow for the safe movement of authorized emergency vehicles. Usually this type of signal is installed on the highway at the entrance into a fire station or other emergency facility. The signal assures protected entrance onto the highway for the emergency vehicle. When not providing for this movement, the signal either operates continuously, consistent with the requirements for a conventional traffic signal, or displays continuous green (allowed at nonintersection locations only). At least two identical displays are required per approach.

hazard identification beacon A beacon that supplements a warning or regulatory sign or marking. The display is a flashing yellow indication. These beacons are not used with “stop”, “yield”, or “do not enter” signs. A hazard identification beacon is energized only during those hours when the hazard or regulation exists.

intersection control beacon (flashing beacon) A secondary control device, generally suspended over the center of an intersection, that supplements intersection warning signs and stop signs. One display per approach may be used but two displays per approach are desirable. Intersection control beacons are installed only at an intersection to control two or more directions of travel.

lane control signal (reversible lanes) A special overhead signal that permits, prohibits, or warns of impending prohibition of lane use.

moveable bridge signal (drawbridge signal) A signal installed to notify traffic to stop when the bridge is opened for waterborne traffic. Moveable bridge signals display continuous green when the roadway is open to vehicular traffic.

overlapped displays Overlapped displays allow a nonconflicting traffic movement to run with another phase. Most commonly, a minor street’s exclusive right-turn phase is overlapped with the nonconflicting major street’s left-turn phase. An overlapped display can be terminated after the parent phase terminates. An overlapped display programmed for two or more parent phases continues to display until all of the parent phases have terminated.

pedestrian signal An adaptation of a conventional traffic signal installed at established pedestrian crossings. It is used to create adequate gaps in the vehicular movement to allow for safe pedestrian crossings. When not operating as a pedestrian signal, the system operates consistent with the requirements for an emergency vehicle signal.

portable traffic signal A type of conventional traffic signal used in work zones to control traffic. It is typically used on two-way, two-lane highways where one lane has been closed for roadwork. The traffic signal provides alternating right of way assignments for conflicting traffic movements. The signal has an adjustable vertical support with two three-section signal displays and is mounted on a mobile trailer with its own power source.

ramp meter signal A signal used to control the flow rate of traffic entering a freeway or similar facility. A minimum of two displays is required. When not in use, ramp meter signals are not energized.

speed limit sign beacon A beacon installed with a fixed or variable speed limit sign. The display is a flashing yellow indication.

stop sign beacon A beacon installed above a stop sign. The display is a flashing red indication.

temporary traffic signal A conventional traffic signal used during construction to control traffic at an intersection while a permanent signal system is being constructed. A temporary traffic signal is typically an inexpensive span-wire installation using timber strain poles.

850.04 Procedures

(1) Permit

State statutes (RCWs) require Department of Transportation approval for the design and location of all conventional traffic signals and some types of beacons located on city streets forming parts of state highways. Approval by the Department of Transportation for the design, location, installation, and operation of all other traffic control signals installed on state highways is required by department policy.

The Traffic Signal Permit (DOT Form 242-014 EF) is the formal record of the department’s approval of the installation and type of signal. The permit is completed by the responsible agency and submitted to the Regional Administrator for approval. The region retains a record of the permit approval, complete with supporting data, and a copy is forwarded to the State Traffic Engineer at the Olympia Service Center (OSC). Permits are required for the following types of signal installations:

- Conventional traffic signals
- Emergency vehicle signals
- Hazard identification beacons, when installed overhead at an intersection

- Intersection control beacons
- Lane control signals
- Moveable bridge signals
- Portable signals
- Ramp meter signals
- Pedestrian signals
- Temporary signals

Emergency vehicle signals require annual permit renewal. The region's traffic office reviews the installation for compliance with standards. If satisfactory, the permit is renewed by the Regional Administrator by way of a letter to the operating agency. A copy of this letter is also sent to the State Traffic Engineer.

Permits are not required for hazard identification beacons that are not installed overhead at an intersection, speed limit sign beacons, stop sign beacons, and lane assignment signals at toll facilities.

When it is necessary to increase the level of control, such as changing from an intersection control beacon to a conventional traffic signal, a new permit application is required. If the change results in a reduction in the level of control, as in the case of converting a conventional signal to a flashing intersection beacon, or if the change is the removal of the signal, submit the "Report of Change" portion of the traffic signal permit to the Regional Administrator with a copy to the State Traffic Engineer.

(2) Responsibility for Funding, Construction, Maintenance, and Operation

Responsibility for the funding, construction, maintenance, and operation of traffic signals on state highways has been defined by legislative action and transportation commission resolutions. See Figure 850-3. Responsibilities vary depending on location, jurisdiction, and whether or not limited access control has been established. Limited access as used in this chapter refers to full, partial, or modified limited access control as identified in the "Master Plan for Limited Access Highways Route Listing".

(a) **Inside the corporate limits of cities with a population of less than 22,500.** The Department of Transportation is responsible for funding, construction, maintenance, and operation of traffic signals.

(b) **Inside the corporate limits of cities with a population of 22,500 or greater where there is no established limited access control.** The city is responsible for the funding, construction, maintenance, and operation of traffic signals.

(c) **Inside the corporate limits of cities with a population of 22,500 or greater where there is established limited access control.** The Department of Transportation is responsible for funding, construction, maintenance, and operation of traffic signals.

(d) **Outside the corporate limits of cities and outside established limited access control areas.** The Department of Transportation is responsible for funding, construction, maintenance, and operation of a signal when a new state highway crosses an existing county road. The Department of Transportation is responsible for only the maintenance and operation when a new county road intersects an existing state highway. The county is responsible for the construction costs of the signal and associated illumination. When it is necessary to construct a traffic signal at an existing county road and state highway intersection, the construction cost distribution is based on the volume of traffic entering the intersection from each jurisdiction's roadway. The county's share of the cost, however, is limited to a maximum of fifty percent. The state is responsible for maintenance and operation. See WAC 468-18-040 for details.

(e) **Outside the corporate limits of cities and inside established limited access control areas**. The Department of Transportation is responsible for funding, construction, maintenance, and operation of traffic signals.

(f) **Emergency Vehicle Signals**. The emergency service agency is responsible for all costs associated with emergency vehicle signals.

(g) **Third Party Agreement Signals**. At those locations where the Department of Transportation is responsible for signals and agrees that the proposed signal is justified but where funding schedules and priorities do not provide for the timely construction of the signal requested by others, the following rules apply:

- The third party agrees to design and construct the traffic signal in conformance with the Department of Transportation's standards.
- The third party agrees to submit the design and construction documents to the Department of Transportation for review and approval.
- The third party obtains a traffic signal permit.

850.05 Signal Warrants

The requirements for traffic signal warrants are in the MUTCD. A signal warrant is a minimum condition in which a signal may be installed. Satisfying a warrant does not mandate the installation of a traffic signal. The warranting condition indicates that an engineering study, including a comprehensive analysis of other traffic conditions or factors, is required to determine whether the signal or another improvement is justified. There are eleven warrants for conventional traffic signal installations. These warrants are as follows:

- Warrant 1 Minimum vehicular volume
- Warrant 2 Interruption of continuous traffic
- Warrant 3 Minimum pedestrian volume
- Warrant 4 School crossings
- Warrant 5 Progressive movement
- Warrant 6 Accident experience
- Warrant 7 Systems
- Warrant 8 Combination of warrants
- Warrant 9 Four Hour Volumes
- Warrant 10 Peak Hour Delay
- Warrant 11 Peak Hour Volume

Warrants 1, 2, 9, and 11 of the MUTCD allow a reduction in the major street vehicle volume requirements when the 85th percentile speed exceeds 40 mph. This provision only acknowledges a difference in driver behavior on higher speed roadways. It does not imply that traffic signals are always the most effective solution on these facilities. A proposal to install a traffic signal on any state route with a posted speed of 45 mph or higher requires an alternatives analysis. See Chapter 910. A proposal to install a traffic signal on a high speed highway requires Olympia Service Center Design Office review and concurrence.

Warrant 6, Accident experience, is used when the types of accidents are correctable by the installation of a traffic signal. Correctable accidents typically are angle and side impact collisions with turning or entering vehicles.

Rear-end, sideswipe, and single vehicle accidents are usually not correctable with the installation of a traffic signal and are only used in special circumstances to satisfy the requirements of the accident warrant. In the project file, include an explanation of the conditions justify using these types of accidents to satisfy the accident warrant.

850.06 Conventional Traffic Signal Design

(1) General

The goal of any signal design is to assign right of way in the most efficient manner possible and still be consistent with traffic volumes, intersection geometrics, and safety.

(2) Signal Phasing

As a general rule, although there are exceptions, the fewer signal phases the more efficient the operation of the traffic signal. The number of phases required for safe, efficient operation is related to the intersection geometrics, traffic volumes, the composition of the traffic flow, turning movement demands, and the level of driver comfort desired. The traffic movements at an intersection have been standardized to provide a consistent system for designing traffic signals. See Figure 850-4 for standard intersection movements, signal head numbering, and the standard phase operation. Figure 850-5 shows the phase diagrams for various signal operations.

(a) **Level of Service.** The efficiency of a traffic signal is measured differently than highways. While highways use the number and width of lanes and other factors to determine capacity and a level of service, traffic signals are measured or rated by the overall delay imposed on the motorists. Phase analysis is the tool used to find the anticipated delay for all movements. These delay values are then equated to a level of service. There are several computer-based programs for determining delay and level of service. Letter designations from “A” to “F” denote the level of service (LOS) with “F” being the worst condition.

In new construction or major reconstruction projects where geometric design can be addressed, a level of service of at least “D” in urban locations and “C” in rural areas is desirable on state highways. These levels of service are a projection of the conditions that will be present during the highest peak hour for average traffic volumes during the design year of the traffic signal’s operation. Special or seasonal events of short duration or holidays, which can generate abnormally high traffic volumes, are not considered in this determination. Provide an explanation in the project file when the desired level of service cannot be obtained.

Intersection level of service can be improved by either adding traffic lanes or eliminating conflicting traffic movements. Intersections can sometimes be redesigned to compress the interior of the intersection by eliminating medians, narrowing lanes, or reducing the design vehicle turning path requirements. This compression reduces the travel time for conflicting movements and can reduce overall delay.

(b) **Left-turn phasing.** Left-turn phasing can be either permissive, protected, or a combination of both that is referred to as protected/permissive.

1. **Permissive left-turn phasing** requires the left turning vehicle to yield to opposing through traffic. Permissive left-turn phasing is used when the turning volume is minor and adequate gaps occur in the opposing through movement. This phasing is more effective on minor streets where providing separate, protected turn phasing might cause significant delays to the higher traffic volume on the main street. On high speed approaches or where sight distance is limited, consider providing a separate left-turn storage lane for the permissive movement to reduce the frequency of rear end type accidents and to provide safe turning movements.

2. **Protected/permissive left-turn phasing** means that the left-turn movements have an exclusive nonconflicting phase followed by a secondary phase when the vehicles are required to yield to opposing traffic. Where left-turn phasing will be installed and conditions do not warrant protected-only operation, consider protected/permissive left-turn phasing. Protected/permissive left-turn phasing can result in increased efficiency at some types of intersections, particularly “Tee” intersections, ramp terminal intersections, and intersections of a two-way street with a one-way street where there are no opposing left movements. Due to the geometry of these types of intersections, neither the simultaneous display of a circular red indication with a green left-turn arrow nor the condition referred to as “yellow trap” occur.

“Yellow trap” occurs on a two-way roadway when the permissive left-turn display changes to protected-only mode on one approach, while the display remains in the permissive mode on the opposite approach where a left turning motorist sees a yellow indication on the adjacent through movement. The motorist believes the opposing through movement also has a yellow display, when, in fact, that movement’s display remains green. It is possible to prevent “yellow trap” by recalling the side street, however, this can lead to inefficient operation and is not desirable.

3. **Protected left-turn phasing** provides the left turning vehicle a separate phase and conflicting movements are required to stop.

Protected phasing is always required for multilane left-turn movements.

Use protected left-turn phasing when left turning type accidents on any approach equal 3 per year, or 5 in two consecutive years. This includes left turning accidents involving pedestrians.

Use protected left-turn phasing when the peak hour turning volume exceeds the storage capacity of the turn lane because of insufficient gaps in the opposing through traffic and one or more of the following conditions are present:

- The 85th percentile speed of the opposing traffic exceeds 45 mph.
- The sight distance of oncoming traffic is less than 250 ft when the 85th percentile speed is 35 mph or below or less than 400 ft if the 85th percentile speeds are above 35 mph.
- The left-turn movement crosses three or more lanes (including right-turn lanes) of opposing traffic.
- Geometry or channelization is confusing.

Typically, an intersection with protected left turns operates with leading left turns. This means that on the major street, the left-turn phases, phase 1 and phase 5, time before the through movement phases, phase 2 and phase 6. On the minor street, the left-turn phases, phase 3 and phase 7, time before phase 4 and phase 8. Lagging left-turn phasing means that the through phases time before the conflicting left-turn phases. In lead-lag left-turn phasing one of the left-turn phases times before the conflicting through phases and the other left-turn phase times after the conflicting through phases. In all of these cases, the intersection phasing is numbered in the same manner. Leading, lagging, and lead-lag left-turn phasing are accomplished by changing the order in which the phases time internally within the controller.

(c) **Multilane left-turn phasing.** Multilane left turns can be effective in reducing signal delay at locations with high left turning volumes or where the left-turn storage area is limited longitudinally. At locations with closely spaced intersections, a two-lane left-turn storage area might be the only solution to prevent the left-turn volume from backing up into the adjacent intersection. Consider the turning paths of the vehicles when proposing multilane left turns. At smaller intersections the opposing left turn might not be able to turn during the two-lane left-turn phase and it might be necessary to reposition this lane. If the opposing left turns cannot time together the reduction in delay from the two-lane left-turn phase might be nullified by the requirement for separate opposing left-turn phase. Figure 850-6 shows two examples of two-lane left with opposing single left arrangements.

A two-lane exit is required for the two-lane left-turn movements. In addition, this two-lane exit must extend well beyond the intersection. A lane reduction on this exit immediately beyond the intersection will cause delays and backups into the intersection because the left turning vehicles move in dense platoons and lane changes are difficult. See Chapter 910 for the restrictions on lane reductions on intersection exits.

(d) **Right-turn phasing.** Right-turn overlapped phasing can be considered at locations with a dedicated right-turn lane where the intersecting street has a complimentary protected left-turn movement and U-turns are prohibited. Several right-turn overlaps are shown in the Phase Diagrams in Figure 850-5. The display for this movement is dependent on whether a pedestrian movement is allowed to time concurrently with the through movement adjacent to the right-turn movement.

For locations with a concurrent pedestrian movement, use a five section signal head consisting of circular red, yellow, and green displays with yellow and green arrow displays. Connect the circular displays to the through phase adjacent to the right-turn movement and connect the arrow displays to the complimentary conflicting minor street left-turn phase.

For locations without a concurrent pedestrian movement, use a three section signal head with all arrow displays or visibility limiting displays (either optically programmed sections or louvered visors) with circular red, yellow arrow, and green arrow displays. This display is in addition to the adjacent through movement displays. Program this display as an overlap to both the left-turn phase and the adjacent through phase.

(e) **Two-lane right-turn phasing.** Two-lane right-turn phasing can be used for an extraordinarily heavy right-turn movement. They can cause operation problems when “right turn on red” is permitted at the intersection. Limited sight distance and incorrect exit lane selection are pronounced and can lead to an increase in accidents. In most cases, a single unrestricted “right turn only” lane approach with a separate exit lane will carry a higher traffic volume than the two-lane right-turn phasing.

(f) **Phasing at railroad crossings.** Railroad preemption phasing is required at all signalized intersections when the nearest rail of a railroad crossing is within 200 ft of the stop bar of any leg of the intersection, unless the railroad crossing is rarely used or is about to be abandoned. Preemption for intersections with the railroad crossing beyond 200 ft from the intersection stop line is only considered when the queue on that approach routinely occupies the crossing. Contact the railroad company to determine if this line still actively carries freight or passengers.

Railroad preemption has two distinct intervals; the clearance interval before the train arrives and the passage interval when the train is crossing the intersection leg. During the clearance interval, all phases are terminated and the movement on the railroad crossing leg is given priority. When this movement has cleared the crossing, it is then terminated. During the passage interval, the traffic signal cycles between the movements not affected by the train crossing. See Figure 850-7 for an example of railroad preemption phasing.

Arranging for railroad preemption requires a formal agreement with the railroad company. The region’s Utilities Engineer’s office handles this transaction. Contact this office early in the design stage as this process can be time consuming and the railroad company might require some modifications to the design.

(3) Intersection Design Considerations

Left turning traffic can be better accommodated when the opposing left-turn lanes are directly opposite each other. When a left-turn lane is offset into the path of the approaching through lane, the left turning driver might assume that the approaching vehicles are also in a left-turn lane and fail to yield. To prevent this occurrence, less efficient split phasing is necessary.

Consider providing an unrestricted through lane on the major street of a “T” intersection. This design allows for one traffic movement to flow without restriction.

Skewed intersections, because of their geometry, are difficult to signalize and delineate. When possible, modify the skew angle to provide more normal approaches and exits. The large paved areas for curb return radii at skewed intersections, in many cases, can be reduced when the skew angle is lessened. See Chapter 910 for requirements and design options.

If roadway approaches and driveways are located too close to an intersection, the traffic from these facilities can affect signal operation. Consider restricting their access to “Right In / Right Out” operation.

Transit stop and pull out locations can affect signal operation. See Chapter 1060 for transit stop and pull out designs. When possible, locate these stops and pull outs on the far side of the intersection for the following benefits:

- Minimizes overall intersection conflict, particularly the right-turn conflict.
- Minimizes impact to the signal operation when buses need preemption to pull out.
- Provides extra pavement area where U-turn maneuvers are allowed.
- Eliminates the sight distance obstruction for drivers attempting to turn right on red.
- Eliminate conflict with right-turn pockets.

Large right-turn curb radii at intersections sometimes have negative impacts on traffic signal operation. Larger radii allow faster turning speeds and might move the entrance point farther away from the intersection area. See Chapter 910 for guidance in determining these radii.

At intersections with large right-turn radii, consider locating signal standards on raised traffic islands to reduce mast arm lengths. These islands are primarily designed as pedestrian refuge areas. See Chapter 1025 for pedestrian refuge area and traffic island designs.

Stop bars define the point where vehicles must stop to not be in the path of the design vehicle's left turn. Check the geometric layout by using the turning path templates in Chapter 910 or a computerized vehicle turning path program to determine if the proposed phasing can accommodate the design vehicles. Also, check the turning paths of opposing left-turn movements. In many cases, the phase analysis might recommend allowing opposing left turns to run concurrently, but the intersection geometrics are such that this operation cannot occur.

(4) Crosswalks and Pedestrians

Provide pedestrian displays and push buttons at all signalized intersections unless the pedestrian movement is prohibited. Crosswalks, whether marked or not, exist at all intersections. See Chapter 1025 for additional information on marked crosswalks. If a pedestrian movement will be prohibited at an intersection, provide signing for this prohibition. This signing is positioned on both the near side and far side on the street to be visible to the pedestrians. When positioning these signs for visibility, consider the location of the stop bar where this crossing will be prohibited. Vehicles stopped at the stop bar might obstruct the view of the signing. There are normally three crosswalks at a "T" intersection and four crosswalks at "four legged" intersection. For pedestrian route continuity the minimum number of crosswalks is two at "T" intersections and three for "four legged" intersections.

If a crosswalk is installed across the leg where right or left turning traffic enters, the vehicle display cannot have a green turn arrow indication during the pedestrian "walk" phase. If this cannot be accomplished, provide a separate pedestrian or vehicle turn phase.

Locate crosswalks as close as possible to the intersection, this improves pedestrian visibility for the right-turning traffic. Locate the push buttons no more than five feet from the normal travel path of the pedestrian. Locate the push button no more than 15 ft from the center point at the end of the associated crosswalk. At curb and sidewalk areas, locate the pedestrian push buttons adjacent to the sidewalk ramps to make them accessible to people with disabilities. Figures 850-8a and 850-8b show examples of the push button locations at raised sidewalk locations. When the pedestrian push buttons are installed on the vehicle signal standard, provide a paved path, not less than 4 ft in width, from the shoulder or sidewalk to the standard. If access to the signal standard is not possible, install the push buttons on Type PPB push button posts or on Type PS pedestrian display posts. When pedestrian push buttons are installed behind guardrail, use Type PPB posts. Position these posts so that the push button is not more than 1.5 ft from the face of the guardrail.

(5) Control Equipment

Controller assemblies can be either Type 170 controllers or National Electrical Manufacturers Association (NEMA) controllers with dual ring; eight vehicle phase, four pedestrian phase, four overlap, operational capabilities. From a design perspective, identical operation can be obtained from either controller. Specify the Type 170 unless the region's policy is to use NEMA controllers.

In situations where it is necessary to coordinate the traffic movements with another agency, it is necessary for one of the agencies to be responsible for the operation of the traffic signal, regardless of which agency actually owns and maintains the signal. This is accomplished by negotiating an agreement with the other agency. At a new intersection, where the state owns the signal but another agency has agreed to operate the signal, the controller must be compatible with that agency's system.

When Type 170 controllers are used, but it is necessary to coordinate the state owned and operated signals with another jurisdiction's system using NEMA controllers, use compatible NEMA controllers installed in Type 170/332 cabinets. Specify a C1 plug connected to a NEMA A, B, C, and D plug adapter for these installations. The Model 210 conflict monitor in the Type 170/332 cabinet can be used with a NEMA controller by changing a switch setting. The Type 12 NEMA conflict monitor is not used in this configuration. It does not fit in a Type 170/332 cabinet and the operation is not compatible. When a NEMA cabinet is used, specify rack-mountings for the loop detector amplifiers and the preemption discriminators.

Coordinate with the region's electronics technician to determine the optimum controller cabinet location and the cabinet door orientation. The controller cabinet is positioned to provide maintenance personnel access. At this location, a clear view of the intersection is desirable. Avoid placing the controller at locations where it might block the view of approaching traffic for a motorist turning right on red. Avoid locating the controller where flooding might occur or where the cabinet might be hit by errant vehicles. If possible, position the controller where it will not be affected by future highway construction.

If a telephone line connection is desired for remote signal monitoring and timing adjustments by signal operations personnel, provide a modem in the controller cabinet and separate conduits and a junction box between the cabinet and the telephone line access point.

Vehicle and pedestrian movements are standardized to provide uniformity in signal phase numbering, signal display numbering, preemption channel identification, detection numbering, and circuit identification. The following are general guidelines for the numbering system:

- Assign phases 2 and 6 to the major street through movements, orienting phase 2 to the northbound or eastbound direction of the major street.
- Assign phases 1 and 5 to the major street protected left-turn movements.
- Assign phases 4 and 8 to the minor street through movements.
- Assign phases 3 and 7 to the minor street protected left-turn movements.
- At "Tee" intersections, assign the movement on the stem of the "Tee" to either phase 4 or phase 8.
- At intersections with four approaches and each minor street times separately, assign the minor streets as phase 4 and 8 and note on the phase diagram that these phases time exclusively.
- Signal displays are numbered with the first number indicating the signal phase. Signal displays for phase 2, for example, are numbered 21, 22, 23,and so on. If the display is an overlap, the designation is the letter assigned to that overlap. If the display is protected/permissive, the display is numbered with the phase number of the through display followed by the phase number of the left-turn phase. A protected/permissive signal display for phase 1 (the left-turn movement) and phase 6 (the compatible through movement), for example, is numbered 61/11. The circular red, yellow, green displays are connected to the phase 6 controller output and the yellow and green arrow displays are connected to the phase 1 controller output.
- Pedestrian displays and detectors are numbered with the first number indicating the signal phase and the second number as either an 8 or 9. Pedestrian displays and detectors 28 and 29, for example, are assigned to phase 2.
- Detection is numbered with the first number representing the phase. Detection loops for phase 2 detectors are numbered 21, 22, 23, and so on.
- Emergency vehicle detectors are designated by letters; phase 2 plus phase 5 operation uses the letter "A", phase 4 plus phase 7 uses the letter "B", phase 1 plus phase 6 uses the letter "C", and phase 3 plus phase 8 uses the letter "D".

(6) Detection Systems

The detection system at a traffic actuated signal installation provides the control unit with information regarding the presence or movement of vehicles, bicycles, and pedestrians. Vehicle detection systems perform two basic functions: queue clearance and the termination of phases. Depending on the specific intersection characteristics, either of these functions can take priority. The merits of each function are considered and a compromise might be necessary.

The vehicle detection requirements vary depending on the 85th percentile approach speed as follows:

- When the posted speed is below 35 mph, provide stop bar detection from the stop bar to a point 30 ft to 35 ft in advance of that location. Assign the stop bar loops to detection input "extension" channels. When counting loops are installed, calculate the distance traveled by a vehicle in two seconds at the 85th percentile speed and position the advance loops at this distance in advance of the stop bar.
- When the posted speed is at or above 35 mph, provide advance detection based on the "dilemma zone detection design". Where installed, stop bar detection extends from the stop bar to a point 30 ft to 35 ft in advance of that location. Stop bar detection is required on minor streets. Assign stop bar detection to "call" channels and assign advance detection-to-detection input "extension" channels.

A dilemma occurs when a person is forced to make a decision between two alternatives. As applied to vehicle detection design, this situation occurs when two vehicles are approaching a traffic signal and the signal indications turn yellow. The motorist in the lead vehicle must decide whether to accelerate and risk being hit in the intersection by opposing traffic or decelerate and risk being hit by the following vehicle. Dilemma zone detection design has been developed to address this problem. This design allows the 90th percentile speed vehicle and the 10th percentile speed vehicle to either clear the intersection safely or decelerate to a complete stop before reaching the intersection. The method of calculating the dilemma zone and the required detection loops is shown in Figure 850-9.

A study of the approach speeds at the intersection is necessary to design the dilemma zone detection. Speed study data is obtained at the approximate location at or just upstream of the dilemma zone. Only the speed of the lead vehicle in each platoon is considered. Speed study data is gathered during off-peak hours in free-flow conditions under favorable weather conditions. Prior speed study information obtained at this location can be used if it is less than one and a half years old and driving conditions have not changed in the area.

When permissive left-turn phasing is installed on the major street with left-turn channelization, include provisions for switching the detector input for future protected left-turn phasing. Assign the detector a left-turn detector number and connect to the appropriate left-turn detector amplifier. Then specify a jumper connector between that amplifier output and the extension input channel for the adjacent through movement detector. The jumper is removed when the left-turn phasing is changed to protected in the future.

In most cases, electromagnetic induction loops provide the most reliable method of vehicle detection. Details of the construction of these loops are shown in the Standard Plans. Consider video detection systems for projects that involve extensive stage construction with numerous alignment changes. Video detection functions best when the detectors (cameras) are positioned high above the intersection. In this position, the effective detection area can be about ten times the mounting height in advance of the camera. When video detection is proposed, consider using Type III signal standards in all quadrants and install the cameras on the luminaire mast arms. High wind can adversely affect the video equipment by inducing vibration in the luminaire mast arms. Areas that experience frequent high winds are not always suitable for video detection.

(7) Preemption Systems

(a) **Emergency vehicle preemption.** Emergency vehicle preemption is provided if the emergency service agency has an operating preemption system. WSDOT is responsible for the preemption equipment that is permanently installed at the intersection for new construction or rebuild projects. The emergency service agency is responsible for preemption emitters in all cases. If the emergency agency requests additional preemption equipment at an existing signal, that agency is responsible for all installation costs for equipment installed permanently at the intersection. These same guidelines apply for a transit agency requesting transit preemption. The standard emergency vehicle system is optically activated to be compatible with all area emergency service agency emitters. Approval by the State Traffic Engineer is required for the installation of any other type of emergency vehicle preemption system.

Optically activated preemption detectors are positioned for each approach to the intersection. These detectors function best when the approach is straight and relatively level. When the approach is in a curve, either horizontal or vertical, it might be necessary to install additional detectors in or in advance of the curve to provide adequate coverage of that approach. Consider the approximate speed of the approaching emergency vehicle and the amount of time necessary for phase termination and the beginning of the preemption phase when positioning these detectors.

(b) **Railroad preemption.** An approaching train is detected either by electrical contacts under the railroad tracks or by motion sensors. The railroad company installs these devices. The region provides the electrical connections between the railroad signal enclosure (called a bungalow) and the preemption phasing in the traffic signal controller. A two-conductor cable is used for the electrical connection. The electrical circuit is connected to a closed “dry” contact using a normally energized relay. When a train is detected, the relay opens the circuit to the traffic signal controller. Contact the railroad to determine the voltage they require for this relay. This will determine the requirements for the isolator at the traffic signal controller. The railroad company’s signal equipment usually operates at 24 volt DC storage batteries charged by a 120 volt AC electrical system. Conduit crossings under railroad tracks are normally jacked or pushed because open excavation is rarely allowed. The usual depth for these crossings is four feet below the tracks but railroad company requirements can vary. Contact the company for their requirements. They, also, will need the average vehicle queue clearance time values in order to finalize the preemption agreement. These values are shown on Figure 850-10.

Flashing railroad signals are usually necessary when railroad preemption is installed at a signalized intersection. Automatic railroad gates are also necessary when train crossings are frequent and the exposure factor is high. Chapter 930 provides guidance on determining the railroad crossing exposure factor. Advance signals, signal supports with displays, are also only installed at locations with high exposure factors. See Figures 850-11a and 850-11b. When the nearest rail at a crossing is within 88 ft of an intersection stop bar on any approach, provide additional traffic signal displays in advance of the railroad crossing. The 88-foot distance provides storage for the longest vehicle permitted by statute (75 ft plus 3 ft front overhang and 4 ft rear overhang) plus a 6 ft down stream clear storage distance.

Light rail transit crossings at signalized intersections also use a form of railroad preemption. Light rail transit makes numerous stops along its route, sometimes adjacent to a signalized intersection. Because of this, conventional railroad preemption detection, which uses constant speed as a factor, is not effective. Light rail transit uses a type of preemption similar to that used for emergency vehicle preemption.

(c) **Transit priority preemption.** Signal preemption is sometimes provided at intersections to give priority to transit vehicles. The most common form of preemption is the optically activated type normally used for emergency preemption. This can be included in mobility projects, but the transit company assumes all costs in providing, installing, and maintaining this preemption equipment. The department's role is limited to approving preemption phasing strategies and verifying the compatibility of the transit company's equipment with the traffic signal control equipment.

(8) Signal Displays

Signal displays are the devices used to convey right of way assignments and warnings from the control mechanism to the motorists and pedestrians. When selecting display configurations and locations, the most important objective is the need to present these assignments and warnings to the motorists and pedestrians in a clear and concise manner. Typical vehicle signal displays are shown in Figures 850-12a through 850-12e. In addition to the display requirements contained in the MUTCD, the following also apply:

- Always provide two identical indications for the through (primary) or predominate movement, spaced a minimum of 8 ft apart when viewed from the center of the approach. At a tee intersection, select the higher volume movement as the primary movement and provide displays accordingly. A green left-turn arrow on a primary display and a green ball on the other primary display do not comply with this rule.
- Use arrow indications only when the associated movement is completely protected from conflict with other vehicular and pedestrian movements. This includes conflict with a permissive left-turn movement.
- Locate displays overhead whenever possible and in line with the path of the applicable vehicular traffic.
- Locate displays a minimum of 40 ft (60 ft desirable) ands a maximum of 150 ft from the stop line.
- Consider installation of a near-side display when the visibility requirements of Table 4-1 of the MUTCD cannot be met.
- Use vertical vehicle-signal display configurations. Horizontal displays are not allowed unless clearance requirements cannot be achieved with vertical displays. Approval by the State Traffic Engineer is required for the installation of horizontal displays.
- Use 12-inch signal sections for all vehicle displays except the lower display for a post-mount ramp-meter signal.
- Use all arrow displays for protected left turns when the left turn operates independently from the adjacent through movement.
- When green and yellow arrows are used in combination with circular red for protected left turns operating independently from the adjacent through movement, use visibility-limiting displays (either optically programmed sections or louvered visors). Contact the local maintenance superintendent, signal operations office, or traffic engineer to ensure correct programming of the head.
- Use either a five section cluster arrangement (dog house) or a five section vertical arrangement.
- Use either Type M or Type N mountings for vehicle display mountings on mast arms. Provide only one type of mounting for each signal system. Mixing mounting types at an intersection is not acceptable except for supplemental displays mounted on the signal standard shaft.
- Use backplates for all overhead mounted displays.
- Use Type E mountings for pedestrian displays mounted on signal standard shafts.
- Consider installing supplemental signal displays when the approach is in a horizontal or vertical curve and the intersection visibility requirements cannot be met.

The minimum mounting heights for cantilevered mast arm signal supports and span wire installations is 16.5 ft from the roadway surface to the bottom of the signal housing or back plate. There is also a maximum height for signal displays. The roof of a vehicle can obstruct the motorist's view of a signal display. The maximum heights from the roadway surface to the bottom of the signal housing with 12-inch sections are shown in Figure 850-1.

Distance	Signal Display	Maximum Height
Signal displays 40 feet from the stop bar	Vertical 3 section	17.3 feet
	Vertical 4 section	16.9 feet
	Vertical 5 section*	16.5 feet
Signal displays 45 feet from the stop bar	Vertical 3 section	19.1 feet
	Vertical 4 section	17.9 feet
	Vertical 5 section*	16.8 feet
Signal displays 50 feet from the stop bar	Vertical 3 section	20.9 feet
	Vertical 4 section	19.7 feet
	Vertical 5 section*	18.5 feet
Signal displays 53 to 150 feet from the stop bar	Vertical 3 section	21.9 feet
	Vertical 4 section	20.7 feet
	Vertical 5 section*	19.6 feet

* Note: The 5 section cluster display is the same height as a vertical 3-section signal display.

Signal Display Maximum Heights
Figure 850-1

Install an advanced signalized intersection warning sign assembly to warn motorists of a signalized intersection when either of the two following conditions exists:

- The visibility requirements in Table 4-1 of the MUTCD are not achievable.
- The 85th percentile speed is 55 mph or higher and the nearest signalized intersection is more than two miles away.

This warning sign assembly consists of a W3-3 sign, two continuously flashing beacons, and sign illumination. Locate the sign in advance of the intersection in accordance with Table II-1 (Condition A) of the MUTCD.

(9) Signal Supports

Signal supports for vehicle displays consist of metal vertical shaft standards (Type I), cantilevered mast arm standards (Type II, Type III, and Type SD Signal Standards), metal strain poles (Type IV and Type V Signal Standards), or timber strain poles. See the Standard Plans. Mast arm installations are preferred because they provide greater stability for signal displays in high wind areas and reduce maintenance costs. Preapproved mast arm signal standard designs are available with arm lengths up to 65 ft. Use mast arm standards for permanent installations unless display requirements cannot be met. Metal strain poles are allowed when signal display requirements cannot be achieved with mast arm standards or the installation is expected to be in place less than 5 years. Timber strain pole supports are generally used for temporary installations that will be in place less than 2 years.

Pedestrian displays can be mounted on the shafts of vehicle display supports or on individual vertical shaft standards (Type PS). The push buttons used for the pedestrian detection system can also be mounted on the shafts of other display supports or on individual pedestrian push button posts. Do not place the signal standard at a location that blocks pedestrian or wheelchair activities. Locate the pedestrian push buttons so they are ADA accessible to pedestrians and persons in wheelchairs.

Terminal cabinets mounted on the shafts of mast arm standards and steel strain poles are recommended. The cabinet provides electrical conductor termination points between the controller cabinet and signal displays that allows for easier construction and maintenance. Terminal cabinets are usually located on the back side of the pole to reduce conflicts with pedestrians and bicyclists.

In the placement of signal standards, the primary consideration is the visibility of signal faces. Place the signal supports as far as practicable from the edge of the traveled way without adversely affecting signal visibility. The MUTCD provides additional guidance for locating signal supports. Initially, lay out the location for supports for vehicle display systems, pedestrian detection systems, and pedestrian display systems independently to determine the optimal location for each type of support. If conditions allow and optimal locations are not compromised, pedestrian displays and pedestrian detectors can be installed on the vehicular display supports.

Another important consideration that can influence the position of signal standards is the presence of overhead and underground utilities. Verify the location of these lines during the preliminary design stage to avoid costly changes during construction.

Mast arm signal standards are designed based on the total wind load moment on the mast arm. The moment is a function of the XYZ value and this value is used to select the appropriate mast arm fabrication plan. The preapproved mast arm fabrication plans are listed in the special provisions. To determine the XYZ value for a signal standard, the cross sectional area for each component mounted on the mast arm is determined. Each of these values is then multiplied by its distance from the vertical shaft. These values are then totaled to determine the XYZ value. All signal displays and mast arm mounted signs, including street name signs, are included in this calculation. The effect of emergency preemption detectors and any required preemption indicator lights are negligible and are not included. For mast arm mounted signs, use the actual sign area to determine the XYZ value. An example of this calculation is shown in Figure 850-13. Cross sectional areas for vehicle displays are shown in Figure 850-2.

Signal Display	Area
Vertical 3 section	8.7 sq ft
Vertical 4 section	11.0 sq ft
Vertical 5 section	13.1 sq ft
5 section cluster	14.4 sq ft

Signal Display Areas
Figure 850-2

Foundation design is a critical component of the signal support. A soils investigation is required to determine the lateral bearing pressure and the friction angle of the soil and whether ground water might be encountered. The XYZ value is used in determining the foundation depth for the signal standard. Select the appropriate foundation depth from Figure 850-13. A special foundation design for a mast arm signal standard is required if the lateral bearing pressure is less than 1000 psf or the friction angle is less than 26 degrees. The regional materials group determines if these unusual soil conditions are present and a special foundation design is required. They then send this information to the OSC Materials Office for confirmation. That office forwards the findings to the OSC Bridge and Structures Office and requests the special foundation design. The Bridge and Structures Office designs foundations for the regions and reviews designs submitted by private engineering groups performing work for the regions.

Steel strain poles are used in span wire installations and are available in a range of pole classes. A pole class denotes the strength of the pole. The loads and resultant forces imposed on strain poles are calculated and a pole class greater than that load is specified. Figures 850-14a and 850-14b show the procedure for determining the metal strain pole class and foundation. Figure 850-15 shows an example of the method of calculation. The foundation depth is a product of the pole class and the soil bearing pressure. A special design is required for metal strain pole or timber strain pole support systems if the span exceeds 150 ft, the tension on the span exceeds 7200 lbs, or the span wire attachment point exceeds 29 ft in height. Contact the OSC Bridge and Structures Office for assistance.

(10) Preliminary Signal Plan

Develop a preliminary signal plan for the project file. Include with the preliminary signal plan a discussion of the problem that is being addressed by the project. Provide sufficient level of detail on the preliminary signal plan to describe all aspects of the signal installation, including proposed channelization modifications. Use a plan scale of 1 inch = 20 feet and include the following information:

- Stop bars
- Crosswalks
- Left-turn radii, including beginning and ending points
- Corner radii, including beginning and ending points
- Vehicle detector locations

- Pedestrian detector locations
- Signal standard types and locations
- Vehicle signal displays
- Pedestrian signal displays
- Phase diagram including pedestrian movements
- Emergency vehicle preemption requirements
- Illumination treatment

Submit a copy of the preliminary signal plan to the State Traffic Engineer for review and comment. When the proposed traffic signal is on an NHS highway, also submit a copy of the preliminary signal plan to the Assistant State Design Engineer for review and concurrence. After addressing review comments, finalize the plan and preserve as noted in the documentation section of this chapter. Prepare the contract plans in accordance with the *Plans Preparation Manual*.

If HQ is preparing the contract plans, specifications, and estimates for the project, submit the above preliminary signal plan with the following additional items:

- Contact person.
- Charge numbers.
- Critical project schedule dates.
- Existing utilities, both underground and overhead.
- Existing intersection layout, if different from the proposed intersection.
- Turning movement traffic counts; peak hour for isolated intersections; and AM, Midday, and PM peak hour counts if there is another intersection within 500 ft.
- Speed study indicating 90th and 10th percentile speeds for all approaches.
- Electrical service location, source of power, and utility company connection requirements.

After the plans, specifications, and estimate are prepared, the entire package is transmitted to the region for incorporation into their contract documents.

(11) Electrical Design

(a) **Circuitry Layout.** Consider cost, flexibility, construction requirements, and ease of maintenance when laying out the electrical circuits for the traffic signal system. Minimize roadway crossings whenever possible.

(b) **Junction Boxes.** Provide junction boxes at each end of a roadway crossing, where the conduit changes size, where detection circuit splices are required, and at locations where the sum of the bends for the conduit run equals or exceeds 360°. Signal standard or strain pole bases are not used as junction boxes. In general, locate junction boxes out of paved areas and sidewalks. Placing the junction boxes within the traveled way is rarely an effective solution and will present long-term maintenance problems. If there is no way to avoid locating the junction box in the traveled way, use traffic-bearing boxes. Avoid placing junction boxes in areas of poor drainage. In areas where vandalism can be a problem, consider junction boxes with locking lids. The maximum conduit capacities for various types of junction boxes are shown in the Standard Plans.

(c) **Conduit.** Use galvanized steel conduit for all underground raceways for the traffic signal installation on state highways. Thick-walled polyvinyl chloride (Schedule 80 PVC) conduit is used by many local agencies for ease of installation. At existing intersections, where roadway reconstruction is not proposed, place these conduits beyond the paved shoulder or behind existing sidewalks to reduce installation costs. With the exception of the 1/2 inch conduit for the service grounding electrode conductor, the minimum size conduit is 1 inch. The minimum size conduit for installations under a roadway is $1^1/4$ inch. Size all conduits to provide 26% maximum conductor fill for new signal installations. A 40% fill area can be used when installing conductors in existing conduits. See Figure 850-16 for conduit and signal conductor sizes.

(d) **Electrical Service and other components.** Electrical service types, overcurrent protection, and other components are covered in Chapter 840.

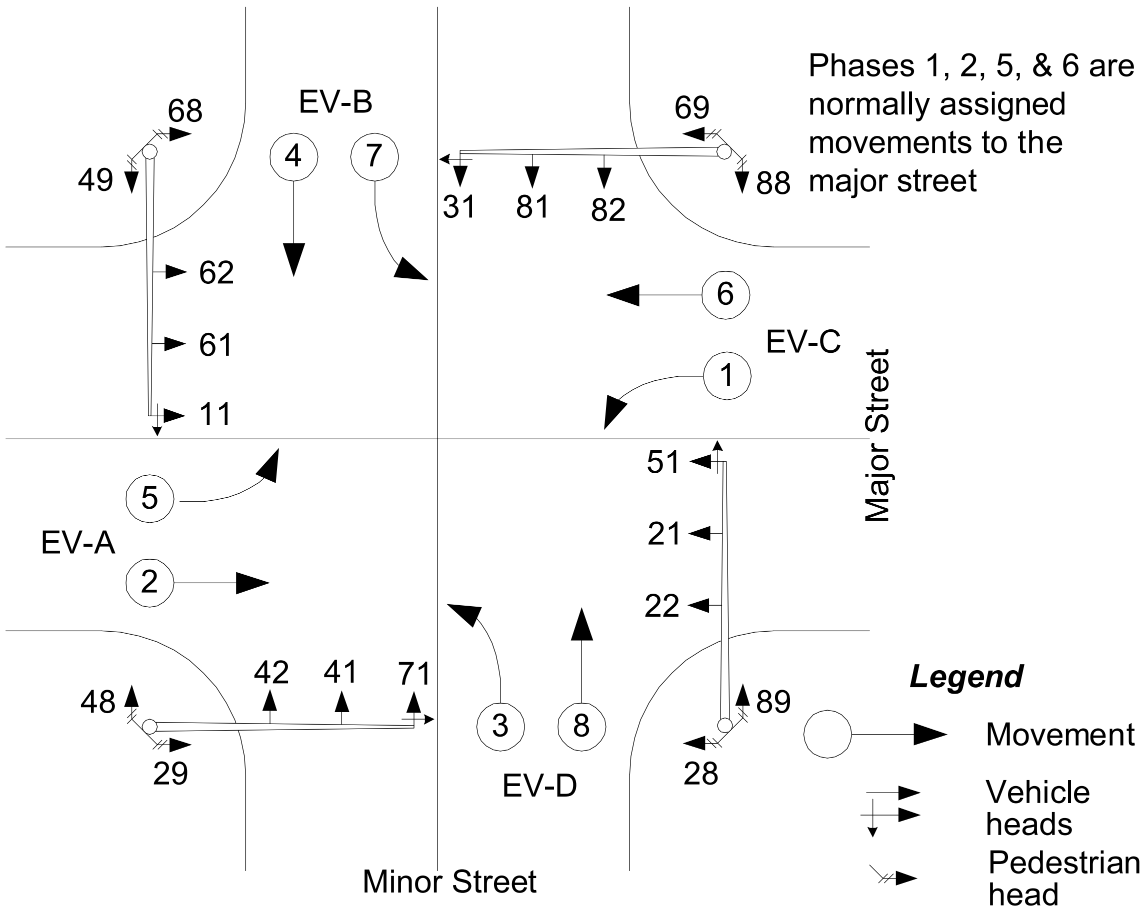
850.07 Documentation

A list of documents that are to be preserved [in the Design Documentation Package (DDP) or the Project File (PF)] is on the following website: http://www.wsdot.wa.gov/eesc/design/projectdev/

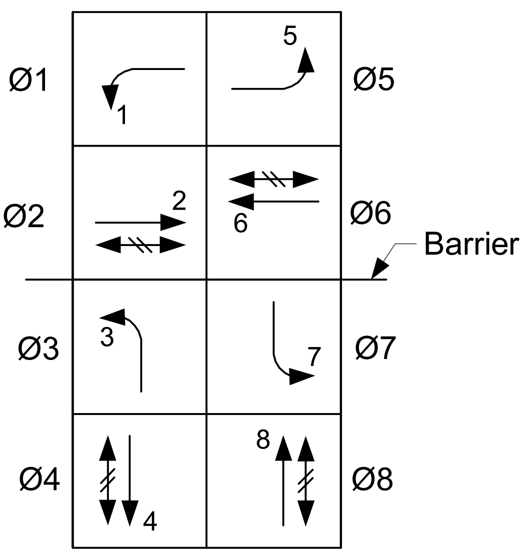
Responsibility for Various Types of Facilities on State Highways				
Area	Responsibility	Emergency vehicle signals	Traffic signals, school signals, & intersection control beacons	Reversible lane signals & moveable bridge signals
Cities with less than 22,500 population	Finance	ESD (1)	State	State
	Construct	ESD (1)	State	State
	Maintain	ESD (1)	State	State
	Operate	ESD (1)	State	State
Cities with 22,500 or greater population	Finance	ESD (1)	City (2)	City (2)
	Construct	ESD (1)	City (2)	City (2)
	Maintain	ESD (1)	City (2)	City (2)
	Operate	ESD (1)	City (2)	City (2)
Beyond corporate limits	Finance	ESD (1)	State Country (3)	State
	Construct	ESD (1)	State	State
	Maintain	ESD (1)	State	State
	Operate	ESD (1)	State	State
Access control	Finance	ESD (1)	State	State
	Construct	ESD (1)	State	State
	Maintain	ESD (1)	State	State
	Operate	ESD (1)	State	State

Notes:
(1) ESD refers to the applicable Emergency Service Department.
(2) State highways without established limited access control. See 850.04(2)b.
(3) See 850.04(2)d.

Responsibility for Facilities
Figure 850-3

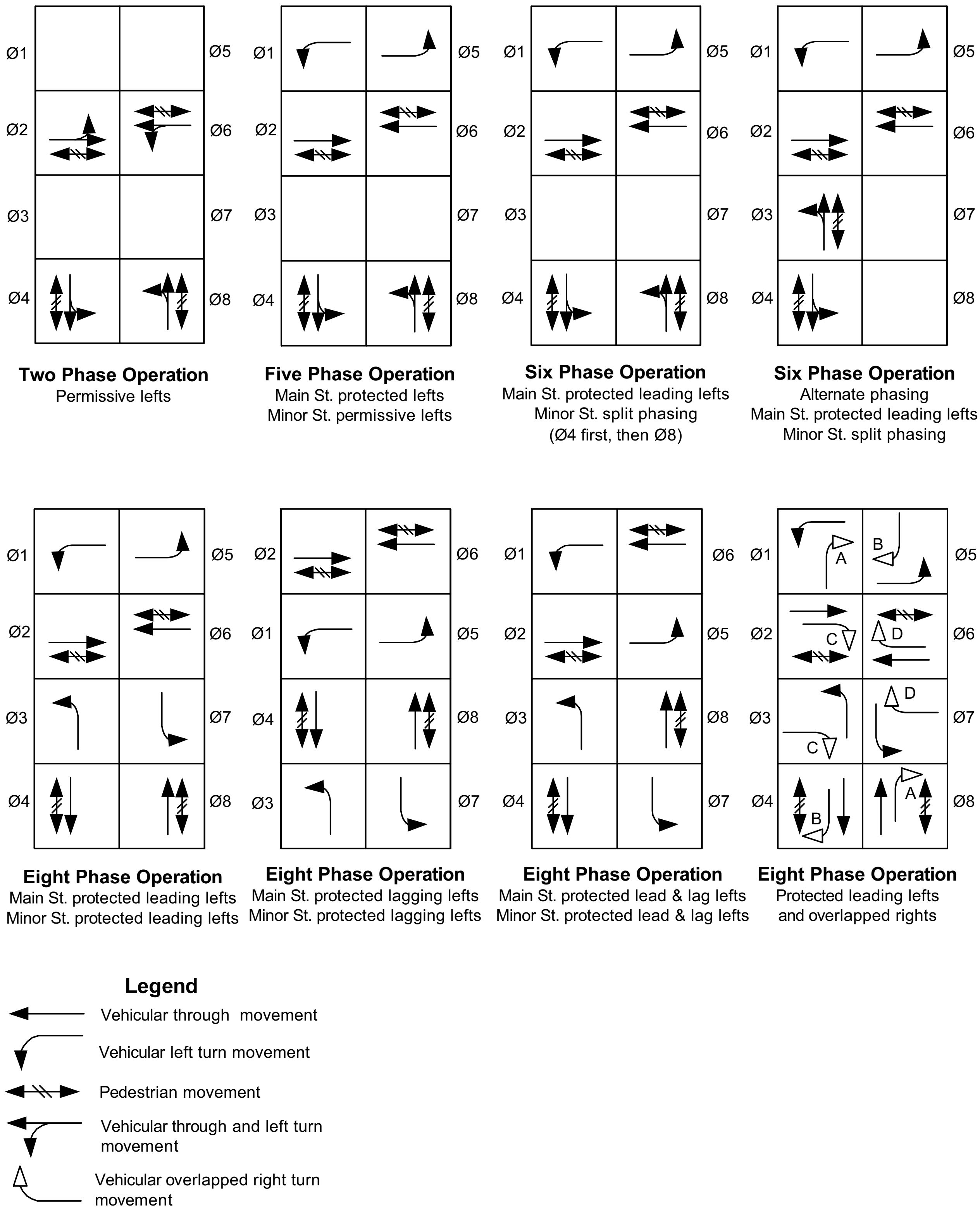


Standard Intersection Movements and Head Numbers

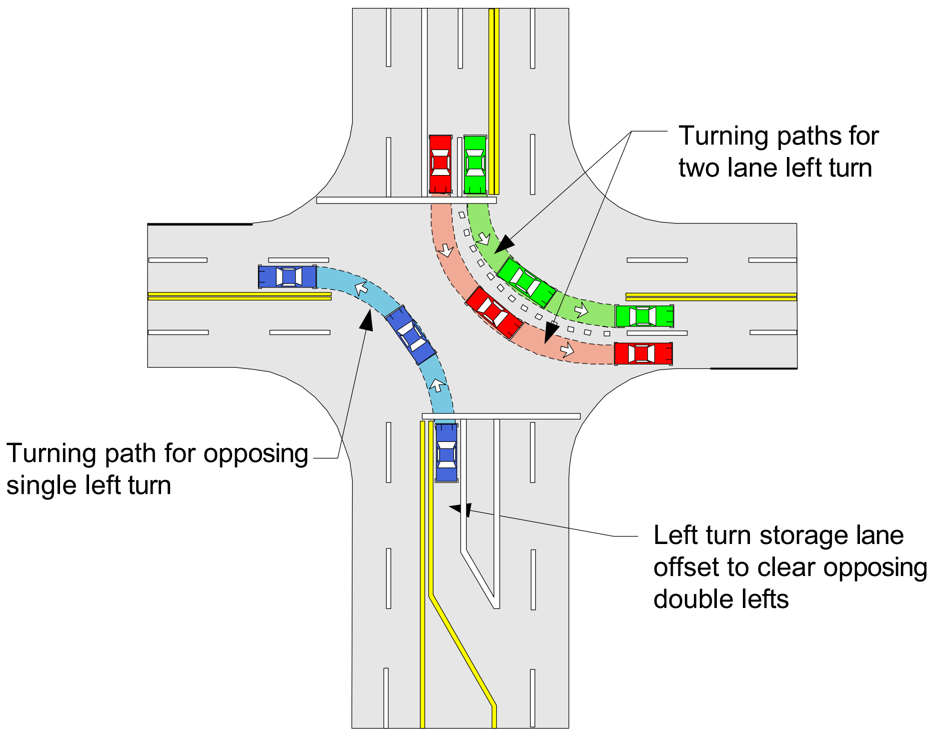


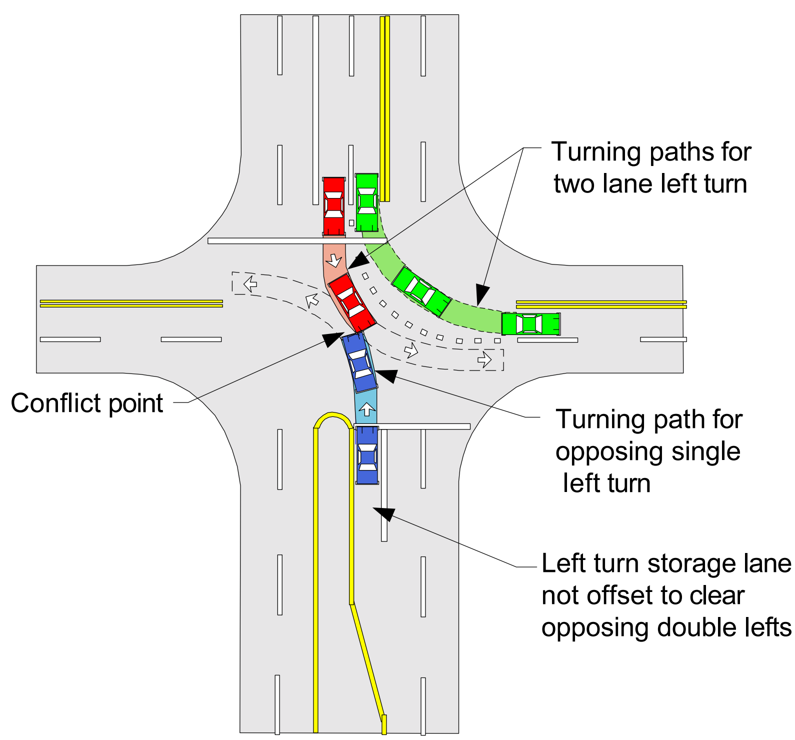
Standard Eight Phase Operation

Standard Intersection Movements and Head Numbers
Figure 850-4

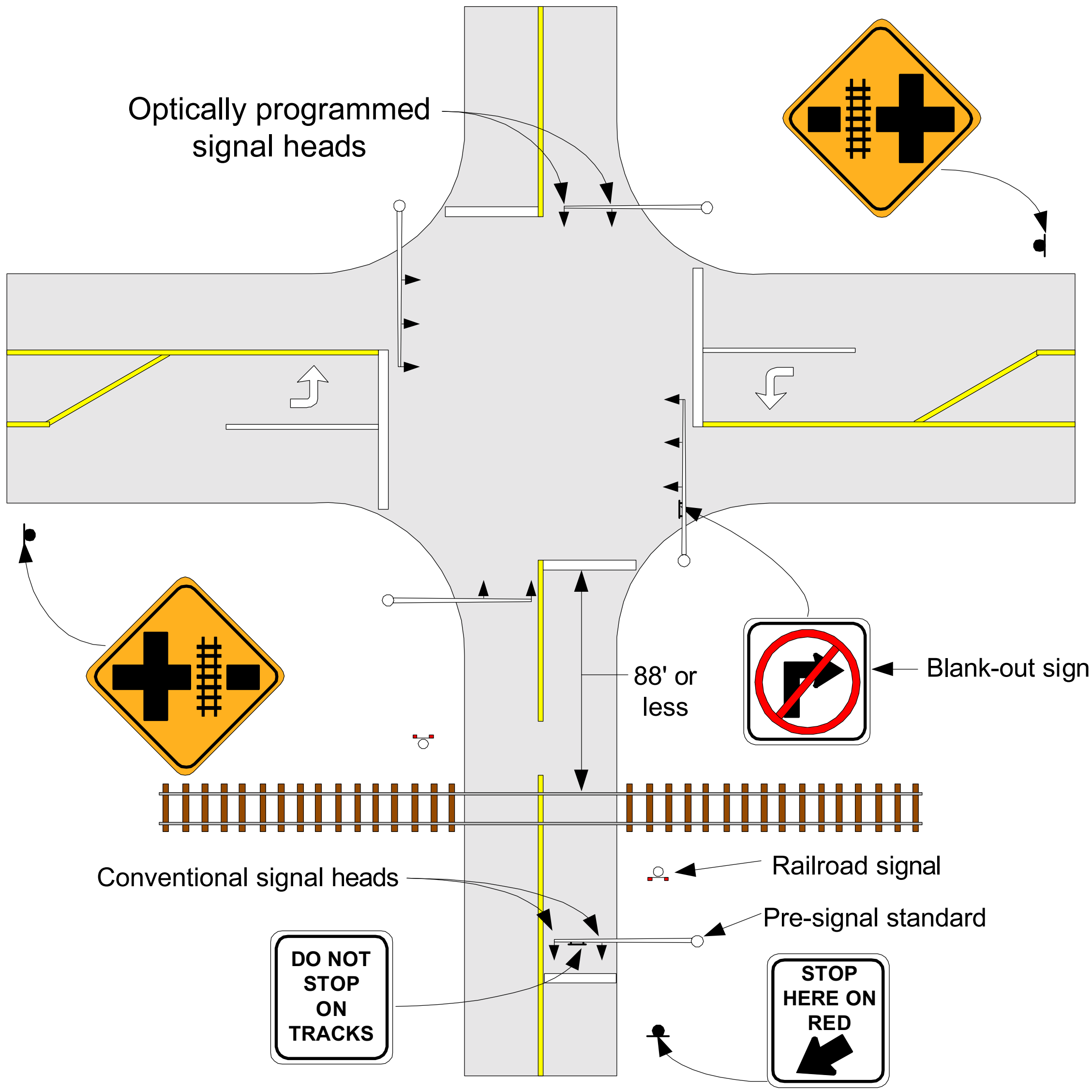


Phase Diagrams — Four Way Intersections
Figure 850-5

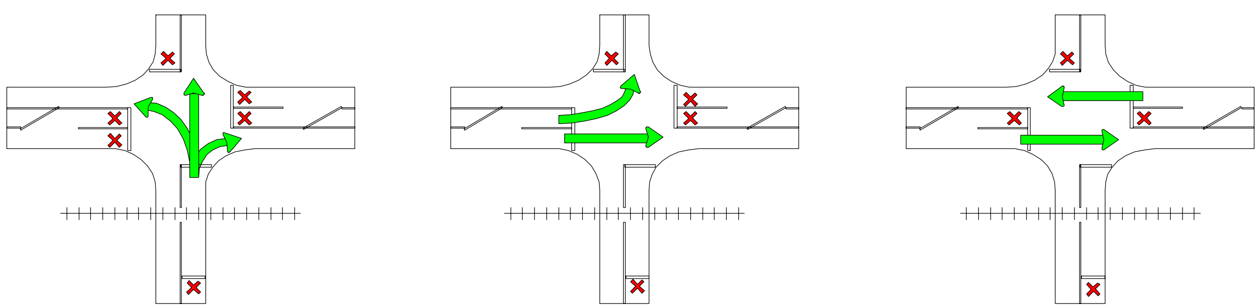




Turn Lane Configuration Preventing Concurrent Phasing
Double Left Turn Channelization
Figure 850-6



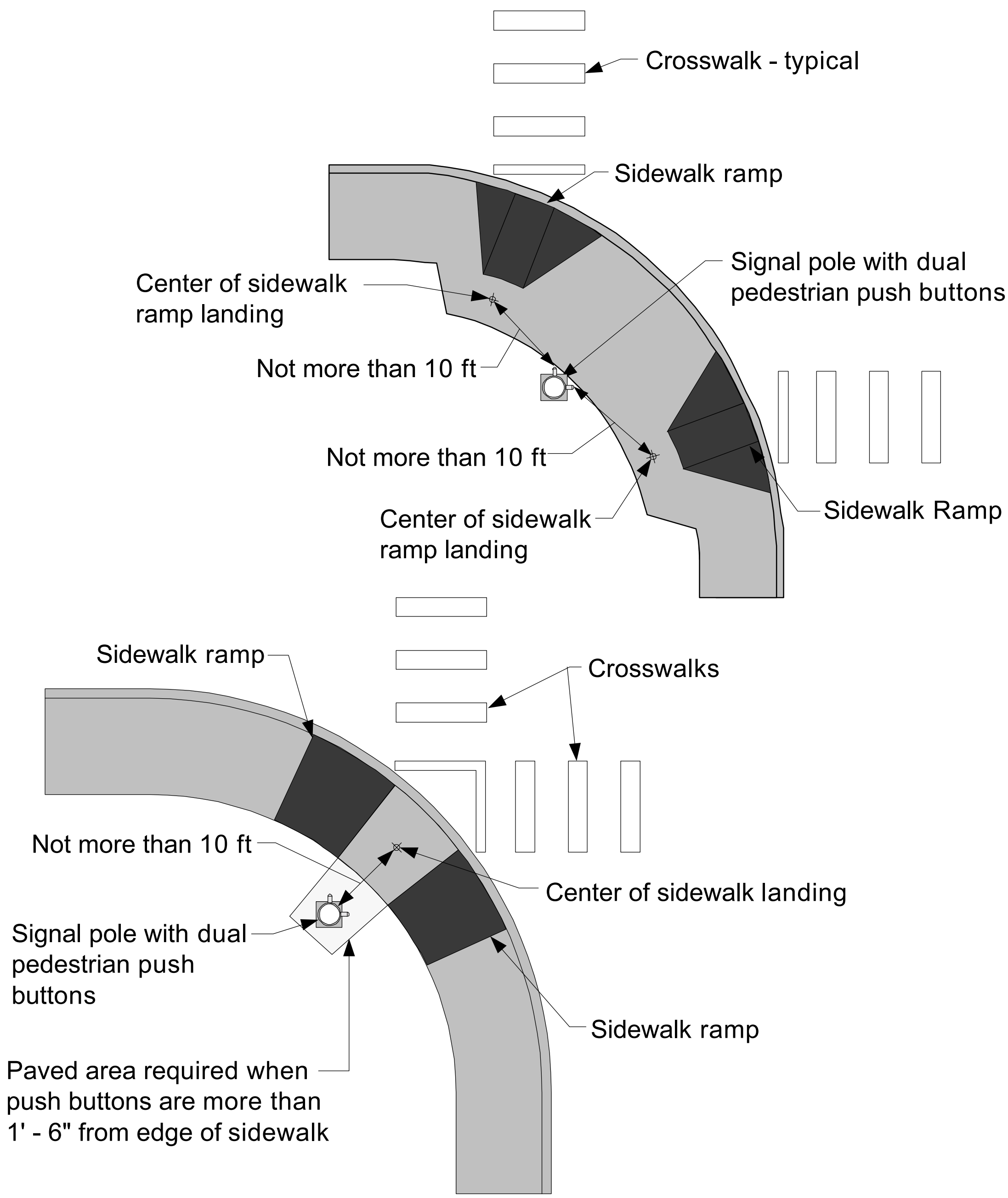
Typical Signal Installation Adjacent to Railroad



Clearance Phase before Train Arrival

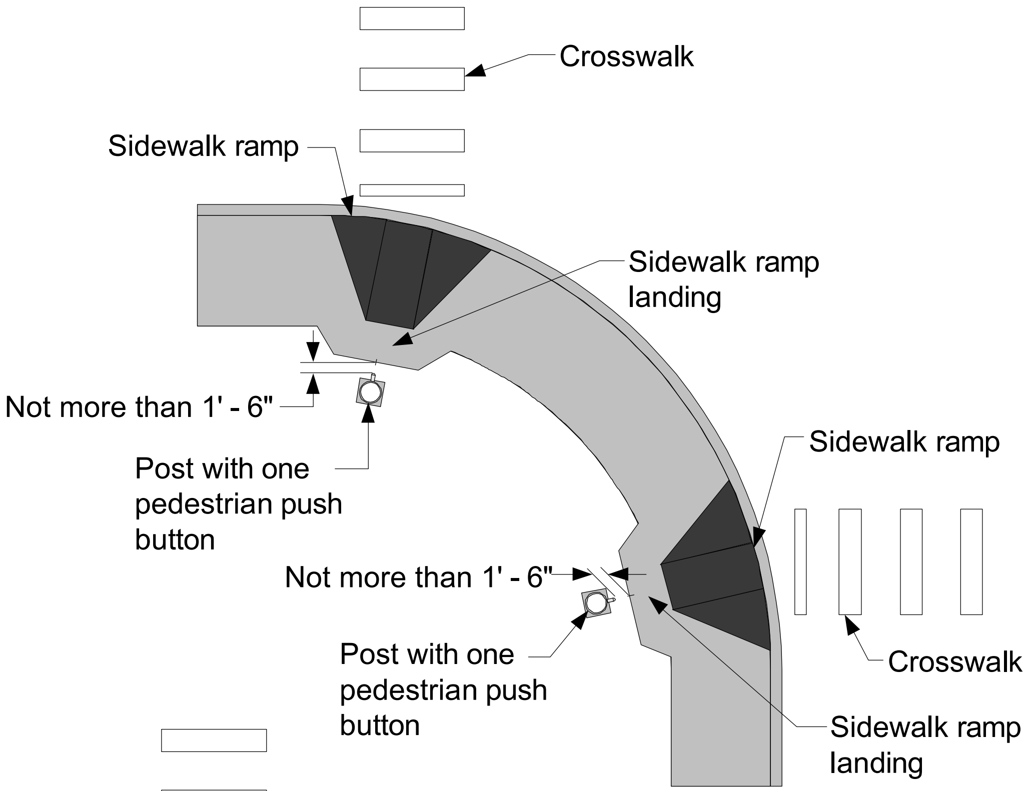
Phase Sequence During Train Crossing

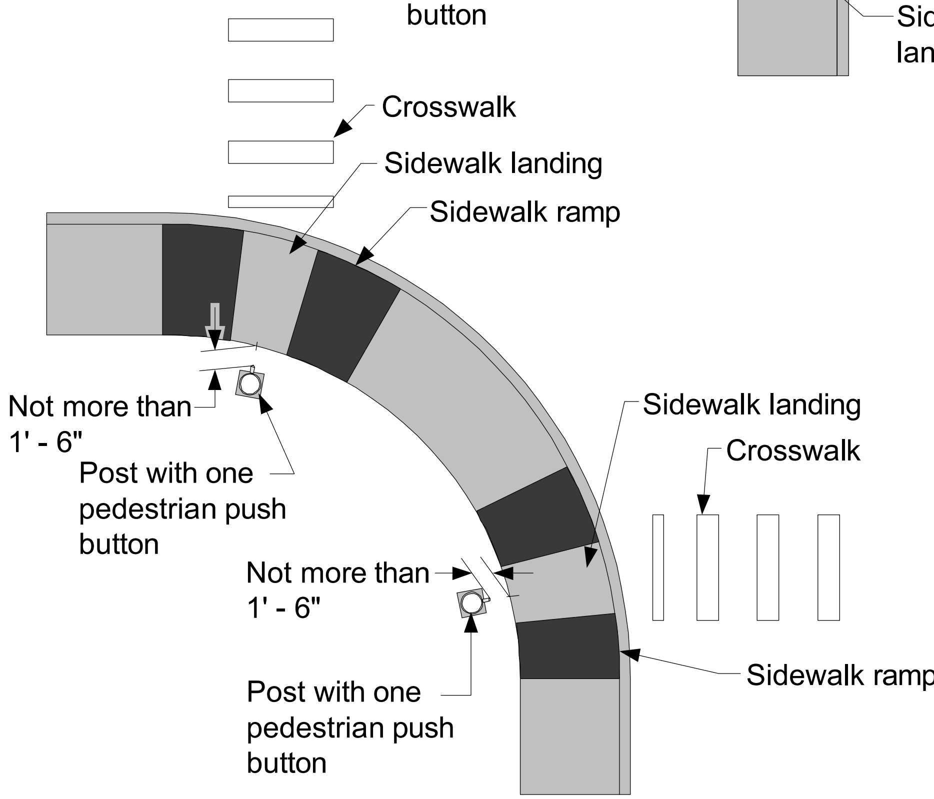
Railroad Preemption Phasing
Figure 850-7



Pedestrian Push Button Locations

Figure 850-8a





Pedestrian Push Button Locations
Figure 850-8b

Where : V_{90} = 90th pecentile speed in feet per second

V_{10} = 10th percentile speed in feet per second

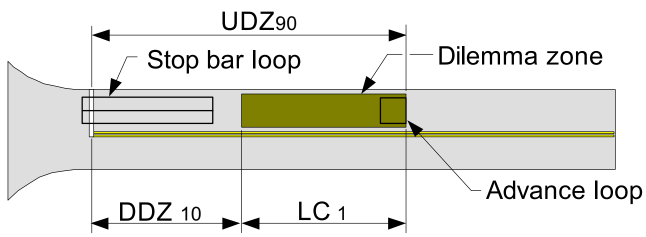
UDZ_{90} = Upstream end of dilemma zone for 90th percentile speed

DDZ_{10} = Downstream end of dilemma zone for 10th percentile speed

LC 1 = V_{10} travel time to downstream DDZ_{10}

LC 2 = V_{10} travel time from 1st loop to 2nd loop

LC 3 = V_{10} travel time from 3rd loop to DDZ_{10}



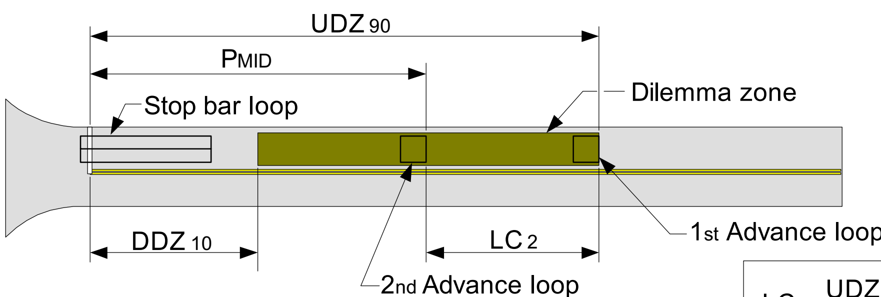
Single Advance Loop Design

When LC_1 is equal to or less than 3 seconds

$$UDZ_{90} = \frac{V_{90}^2}{16} + V_{90}$$

$$DDZ_{10} = \frac{V_{10}^2}{40} + V_{10}$$

$$LC_1 = \frac{UDZ_{90} - DDZ_{10}}{V_{10}}$$

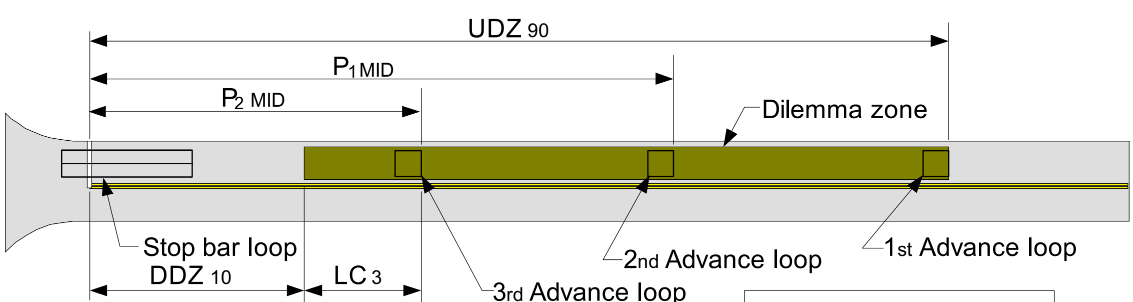


Double Advance Loop Design

When LC_2 is equal to or less than 3 seconds

$$LC_2 = \frac{UDZ_{90} - P_{MID}}{V_{10}}$$

$$P_{MID} = \frac{UDZ_{90} + DDZ_{10}}{2}$$



Triple Advance Loop Design

When LC_2 is greater than 3 seconds

$$LC_3 = \frac{P_2MID - DDZ_{10}}{V_{10}}$$

$$P_1MID = UDZ_{90} - 3V_{10}$$

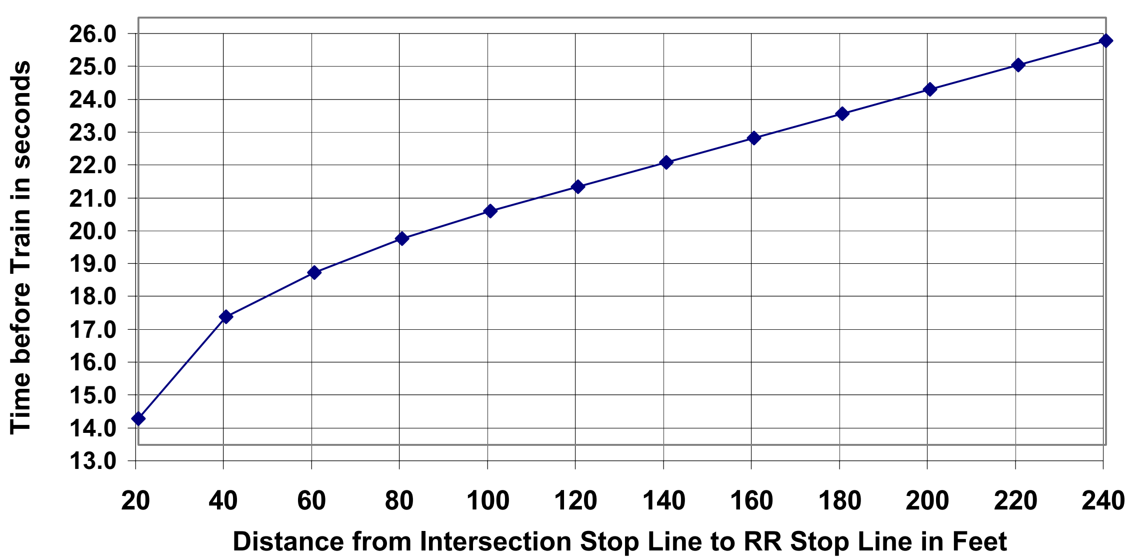
$$P_2MID = UDZ_{90} - 6V_{10}$$

Dilemma Zone Loop Placement

Figure 850-9

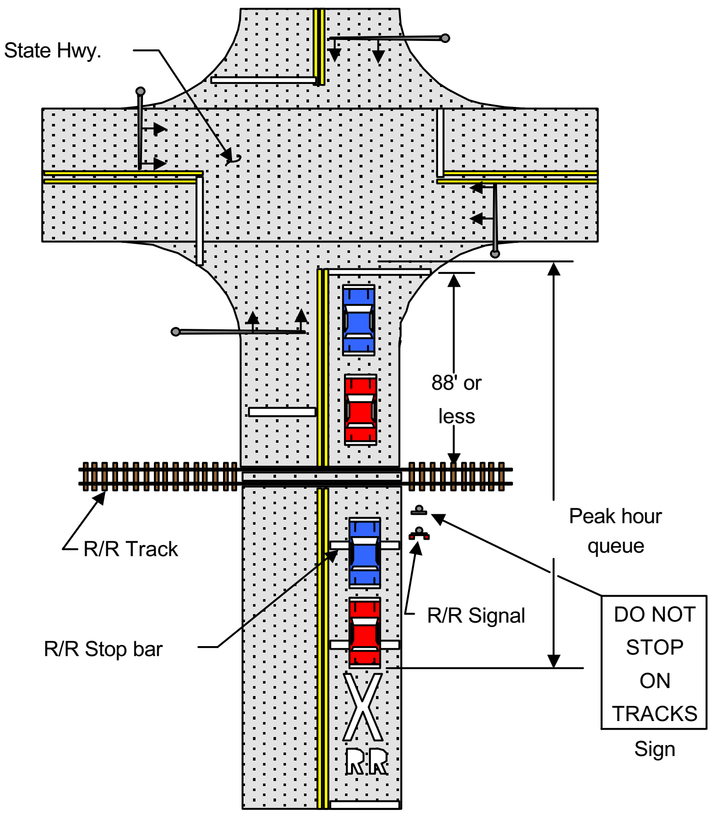
Traffic Signal Railroad Track Clearance Interval Table (Single Track)							
Queue	Start-Up Time	Queue Length	Intersection Clearance	Start-Up Time	Queue Clear Time	Time from PE start to Q	Time Before Train
Vehicles	Seconds	Feet	Seconds	Seconds	Seconds	Seconds	Seconds
A	B	C	D	E	F	G	H
1	3.8	20	10	3.8	3.8	13.8	13.8
2	3.1	40	10	3.1	6.9	16.9	16.9
3	2.7	60	10	2.7	9.6	19.6	18.2
4	2.4	80	10	2.4	12.0	22.0	19.3
5	2.2	100	10	2.2	14.2	24.2	20.1
6	2.1	120	10	2.1	16.3	26.3	20.9
7	2.1	140	10	2.1	18.4	28.4	21.6
8	2.1	160	10	2.1	20.5	30.5	22.3
9	2.1	180	10	2.1	22.6	32.6	23.1
10	2.1	200	10	2.1	24.7	34.7	23.8
11	2.1	220	10	2.1	26.8	36.8	24.6
12	2.1	240	10	2.1	28.9	38.9	25.3

A = Number of Vehicles in the queue.
B = Vehicle startup time.
C = Distance from intersection stop line to R/R gate or R/R stop line. For single track, the stop bar is 20' upstream from the nearest rail.
D = Worst Case intersection clearance (5 seconds mainline green/flashing "don't walk" + 5 seconds yellow/all red = 10 seconds).
E = Startup time for each vehicle by position in the queue.
F = Cumulative startup time, includes the track approach green time (7 seconds minimum).
G = Total time from railroad relay closure until last car in the queue has cleared the intersection stop bar. G = D + F
H = Total time from railroad relay closure until the last car in the queue is 20 ft beyond nearest rail. This assumes a departure speed of 10 MPH. H = G - ((C-40') ÷ 14.7)

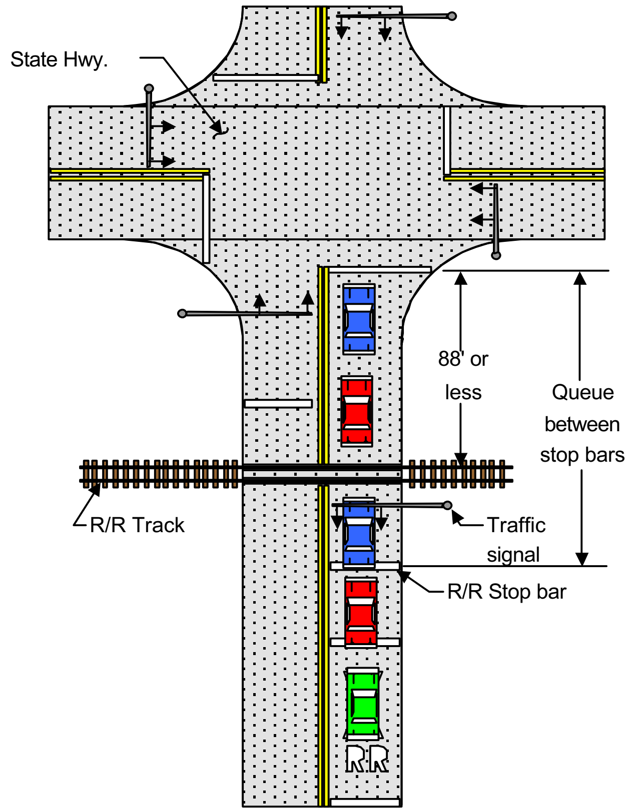


Example: A location where it is 60 ft from stop bar to nearest rail of a single track crossing.
Solution: Enter table at queue length of 80 ft (60 ft + 20 ft to R/R stop bar). Graph value is 19.3 seconds.

Railroad Queue Clearance
Figure 850-10

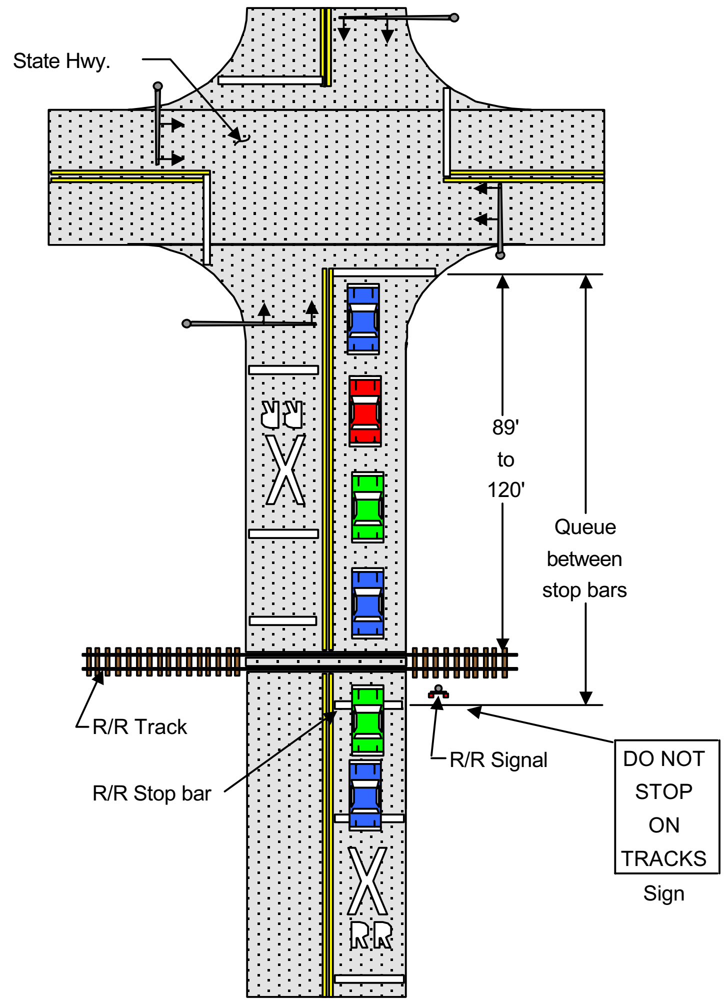


Railroad Crossing
with Low Exposure Factor
(See Chapter 930 for R/R crossing protection guidelines)



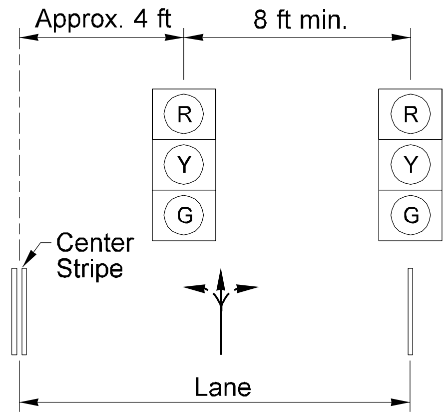
Railroad Crossing
with High Exposure Factor
(See Chapter 930 for R/R crossing protection guidelines)

Intersections With Railroad Crossings
Figure 850-11a

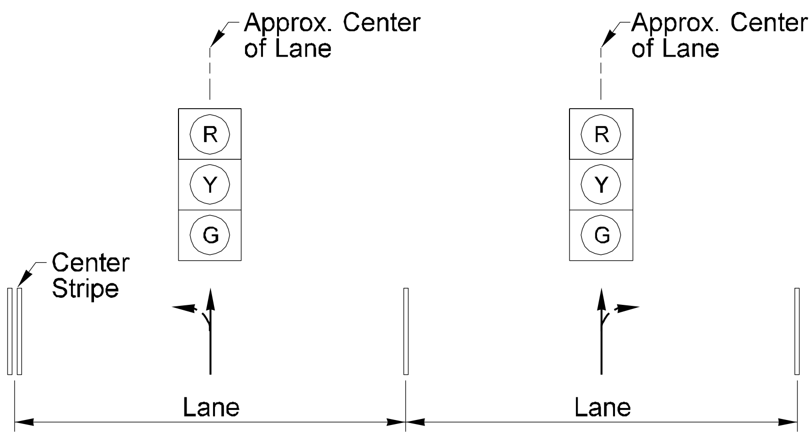


Railroad Crossing more than 88 Ft from Intersection

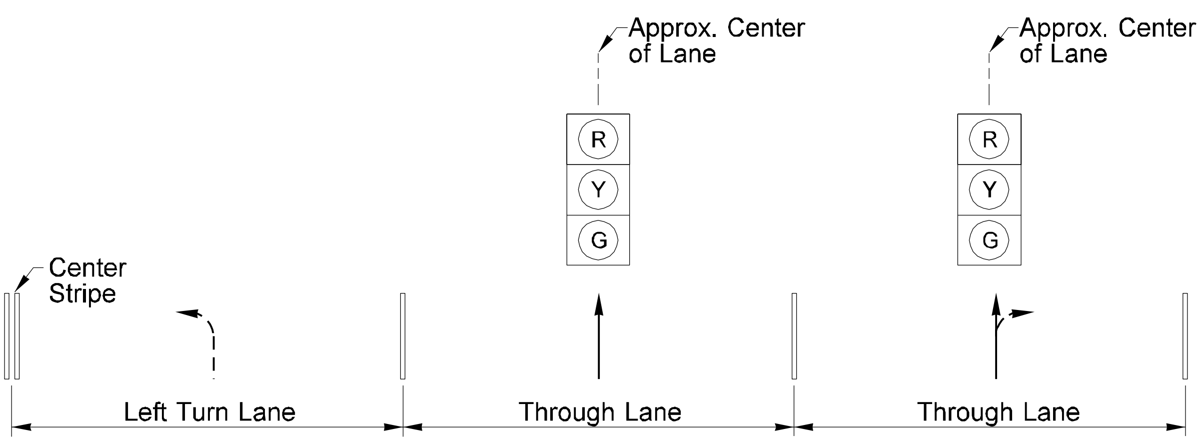
Intersections With Railroad Crossings
Figure 850-11b



One Through Lane
With Permissive Left Turn

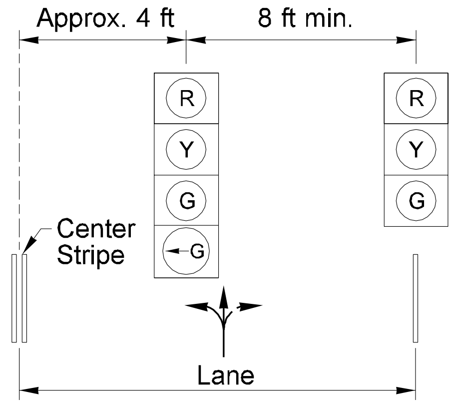


Two Through Lanes
With Permissive Left Turn

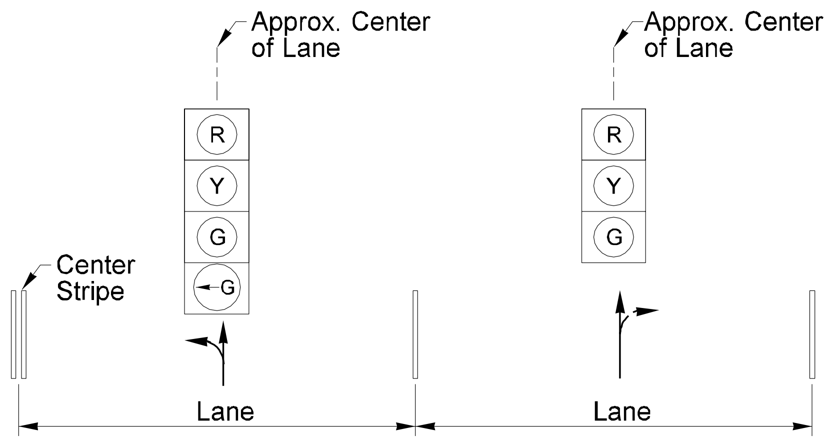


Two Through Lanes and One Left Turn Storage Lane
With Permissive Left Turn

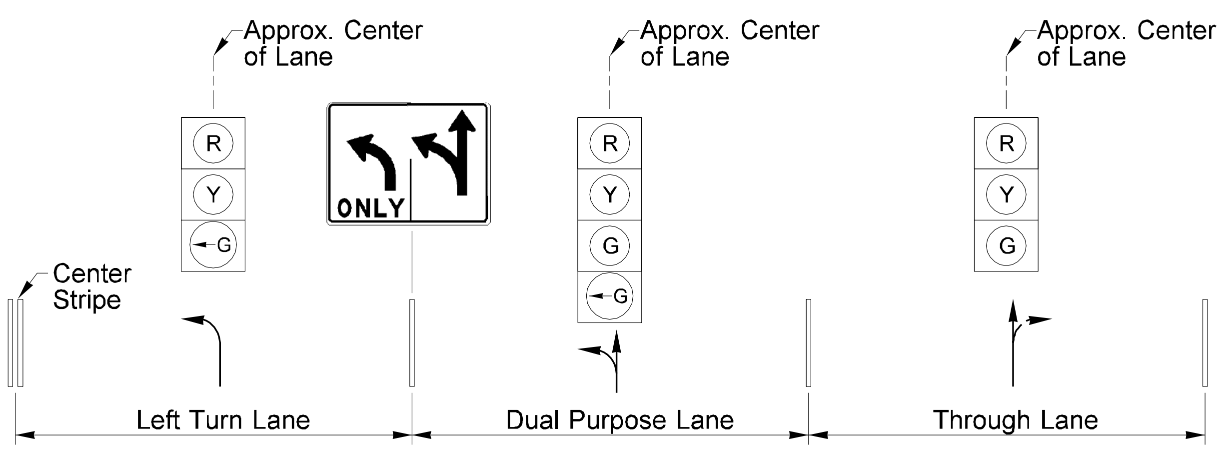
Traffic Signal Display Placements
Figure 850-12a



One Through Lane
With Protected Left Turn Phasing

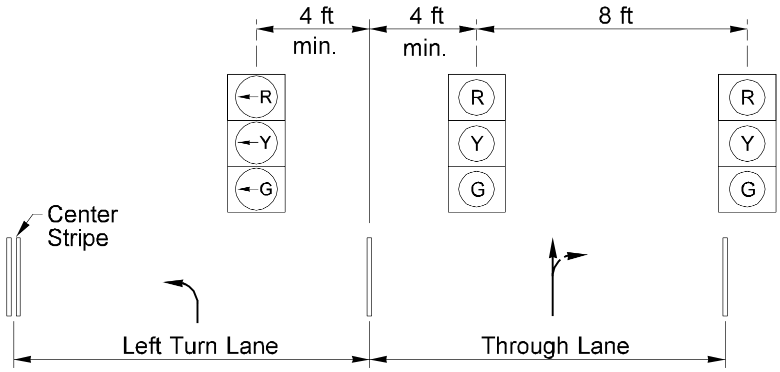


Two Through Lanes
With Split Phasing for Protected Left Turns
(Left turn and through movements terminate together.)



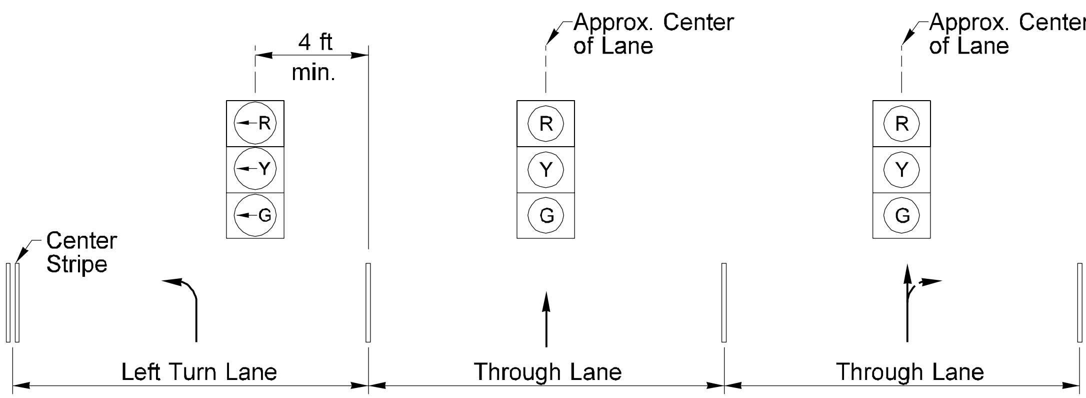
One Through Lane, a Dual Purpose (Left or Through) Lane
and One Left Turn Storage Lane With Split Phasing for Protected Left Turns
(Left turn and through movements terminate together.)

Traffic Signal Display Placements
Figure 850-12b



One Through Lane and One Left Turn Storage Lane
With Protected Left Turn Phasing

(Left turn and through movements terminate independently.)

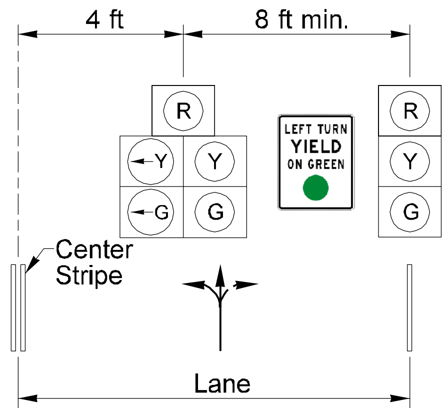


Two Through Lanes and One Left Turn Storage Lane
With Protected Left Turn Phasing

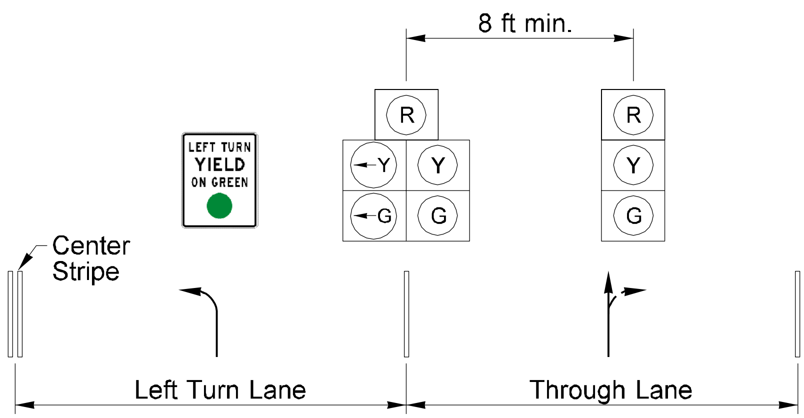
(Left turn and through movements terminate independently.)

Traffic Signal Display Placements

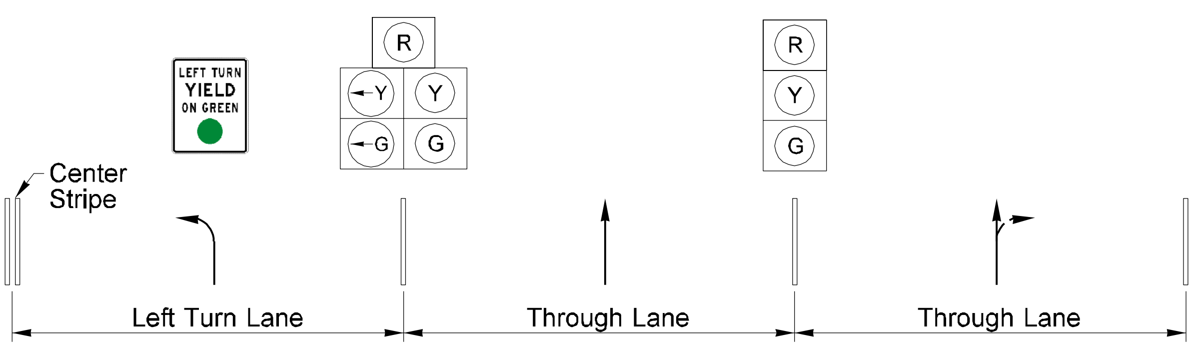
Figure 850-12c



One Through Lane
With Protected / Permissive Left Turn Phasing

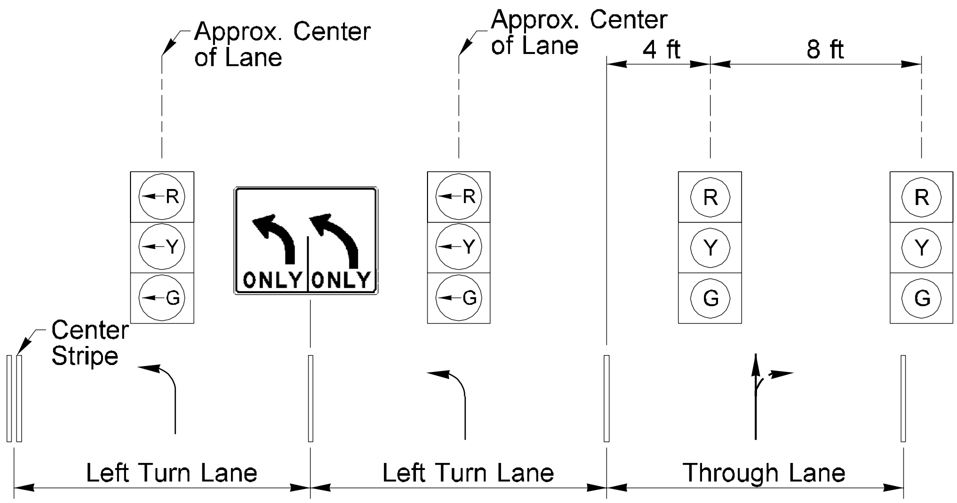


One Through Lane and One Left Turn Storage Lane
With Protected / Permissive Left Turn Phasing



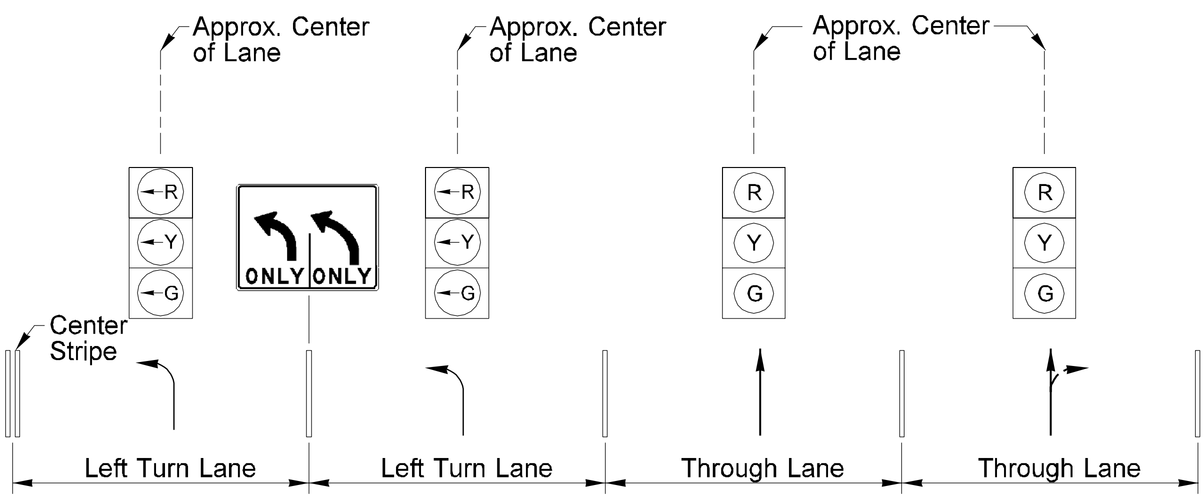
Two Through Lanes and One Left Turn Storage Lane
With Protected / Permissive Left Turn Phasing

Traffic Signal Display Placements
Figure 850-12d



One Through Lane and Two Left Turn Storage Lanes With Protected Left Turn Phasing

(Left Turn and Through Movements Terminate Independently.)

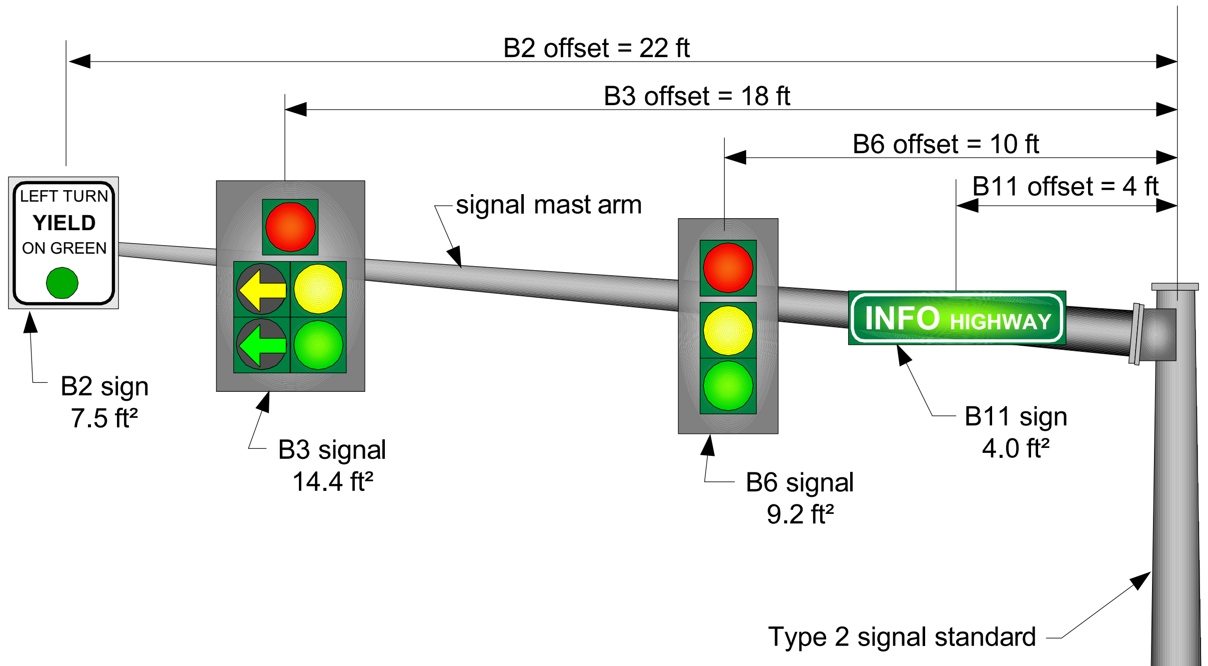


Two Through Lanes and Two Left Turn Storage Lanes With Protected Left Turn Phasing

(Left turn and through movements terminate independently.)

Traffic Signal Display Placements

Figure 850-12e



First

Total windload calculation (XYZ)

B2 area X B2 offset

$7.5\ ft^2 \times 22\ ft = 165.0$

B3 area X B3 offset

$14.4\ ft^2 \times 18\ ft = 259.2$

B6 area X B6 offset

$9.2\ ft^2 \times 10\ ft = 92.0$

B11 area X B11 offset

$4.0\ ft^2 \times 4\ ft = 16.0$

Total XYZ = $532.2\ ft^3$

Then

Determine foundation depth from chart

If the lateral bearing pressure is 1500 psf and the XYZ is $532\ ft^3$,

Then the foundation depth is:

8 ft ~ 3 ft round foundation type
7 ft ~ 3 ft square foundation type
7 ft ~ 4 ft round foundation type

FOUNDATION DEPTH TABLE							
Lateral Bearing Pressure	Foundation Type	XYZ (cubic feet)					
		Type II, III, and SD mast arm standards					
		$600\ ft^3$	$900\ ft^3$	$1200\ ft^3$	$1500\ ft^3$	$1900\ ft^3$	$2300\ ft^3$
1000 psf	3' Round	10'	10'	11'	11'	13'	15'
	3' Square	8'	8'	9'	9'	10'	11'
	4' Round	8'	8'	9'	9'	10'	11'
1500 psf	3' Round	8'	8'	9'	11'	13'	15'
	3' Square	7'	7'	7'	8'	8'	9'
	4' Round	7'	7'	7'	8'	8'	9'
2500 psf	3' Round	6'	6'	7'	11'	13'	15'
	3' Square	6'	6'	6'	6'	7'	7'
	4' Round	6'	6'	6'	6'	7'	7'

Mast Arm Signal Moment and Foundation Depths

Figure 850-13

Selection Procedure

1. Determine span length
.
2. Calculate the total dead load (P) per span. Use 40 pounds per signal section and 6.25 pounds per square foot of sign area.

3. Calculate the average load (G) per span. G = P/n where (n) is the number of signal head assemblies plus the number of signs.

4. Determine cable tension (T) per span. Enter the proper chart with the average load (G) and number of loads (n). If (n) is less than minimum (n) allowed on chart, use minimum (n) on chart.

5. Calculate the pole load (PL) per pole. If only one cable is attached to the pole, the pole load (PL) equals the cable tension (T). If more than one cable is attached, (PL) is obtained by

computing the vector resultant of the (T) values.

6. Select the pole class from the “Foundation Design Table”. Choose the pole class closest to but greater than the (PL) value.

7. Calculate the required foundation depth (D).
   Use the formula: $D = a\frac{DT}{\sqrt{S}}$
   Select the table foundation depth (DT) from the “Foundation Design Table”. Lateral soil bearing pressure (S) is measured in pounds per square foot (psf). The formula value (a) is a variable for the cross-sectional shape of the foundation. The values for these shapes are:
   a = 50 for a 3’ round foundation
   a = 43 for a 4’ round foundation
   a = 41 for a 3’ square foundation
   Round (D) upwards to nearest whole number if 0.10 foot or greater,

8. Check vertical clearance (16.5’ minimum) assuming 29’ maximum cable attachment height and 5% minimum span sag.

Notes:
A special design by the Bridge and Structures Office is required if:
The span length exceeds 150 ft.
The (PL) value exceeds 7200 lbs
The vertical distance between the base plate and the first cable attachment exceeds 29 feet.

1. Charts are based on a cable weight of 3 pounds per foot (1.25 lbs/ft, cable and conductors, 1.75 lbs/ft ice). Total dead load (P) includes weight of ice on sign and signal section.
2. On timber strain pole designs, specify two down guy anchors when the (PL) value exceeds 4500 Lbs.

Foundation Design Table	
Pole Class (Pounds)	Foundation Depth (DT)
1900	6' - 0"
2700	7' - 0"
3700	8' - 0"
4800	9' - 6"
5600	10' - 0"
6300	11' - 0"
7200	12' - 0"

Strain Pole and Foundation Selection Procedure
Figure 850-14a

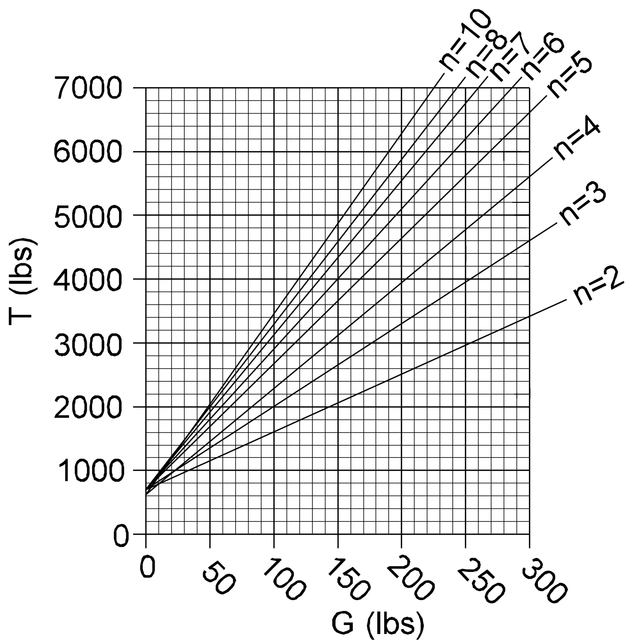


Chart 1 - Span Length 90' and Less

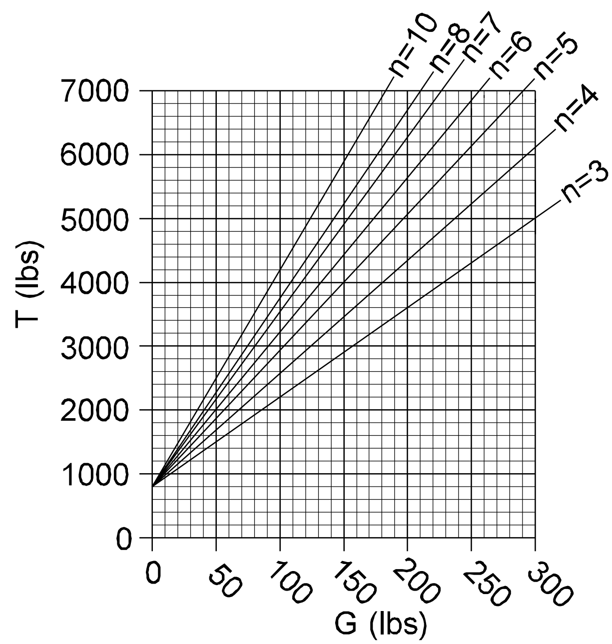


Chart 2 - Span Length 91' to 120'

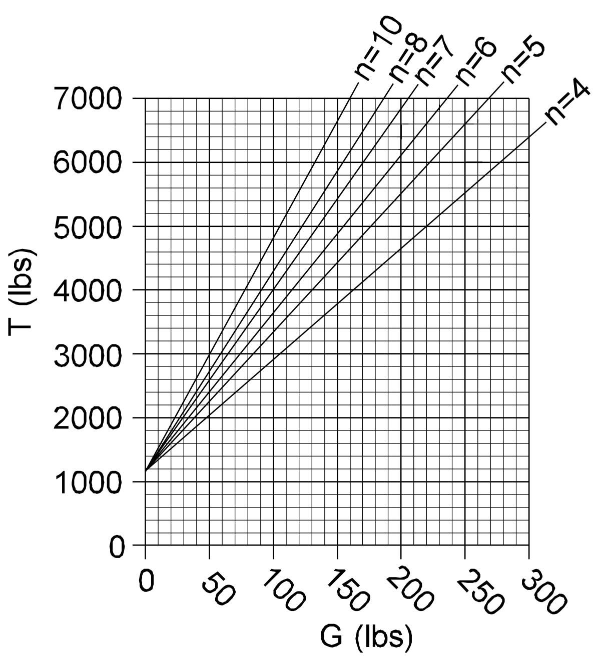
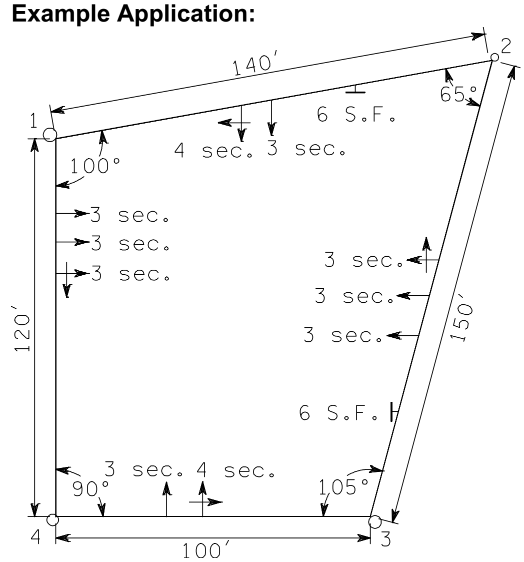


Chart 3 - Span Length 121' to 150'

Strain Pole and Foundation Selection Procedure
Figure 850-14b

Example Application:



Determine the following:

- Cable Tensions (T)
- Pole Loads (PL)
- Pole Classes
- Foundation Depths (D)

Step 1.
Span lengths given above.

Step 2.
Calculate (P) and (G) values.

Span 1-2, n = 3
7 sections x 40 lbs/sec = 280 pounds
6 s.f. sign x 6.25 lbs/s.f. = 38 pounds
Total (P) = 318 pounds
G = P/n = 318/3 = 106 pounds

Span 2-3, n = 4
9 sections x 40 lbs/sec = 360 pounds
6 s.f. sign x 6.25 lbs/s.f. = 38 pounds
Total (P) = 398 pounds
G = P/n = 398/4 = 100 pounds

Span 3-4, n =2
7 sections x 40 lbs/sec = 280 pounds
Total (P) = 280 pounds
G = P/n = 280/2 = 140 pounds

Span 4-1, n = 3
9 sections x 40 lbs/sec = 360 pounds
Total (P) = 360 pounds
G = P/n = 360/3 = 120 pounds

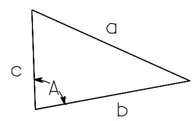
Step 3.
Determine (T) values.

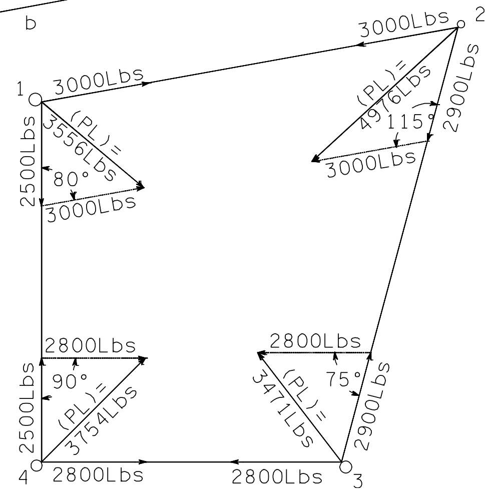
Span	Length	G	Chart	n	min n	T
1-2	140’	106 lbs	III	3	4	3000 lbs
2-3	150’	100 lbs	III	4	4	2900 lbs
3-4	140’	140 lbs	II	2	3	2800 lbs
4-1	120’	120 lbs	II	3	3	2500 lbs

Step 4.

Calculate (PL) values by computing the vector resultant of the (T) values.

$$a = \sqrt{b^2 + c^2 - 2bc(\cos A)}$$





Step 5.
Select the pole class from the Design Table (Figure 850-14b).

Pole Number	(PL)	Pole Class
1	3556 lbs	3700 lbs
2	4976 lbs	5600 lbs
3	3471 lbs	3700 lbs
4	3754 lbs	4800 lbs

Step 6.
Calculate the required foundation depths.
Given: (S) = 1000 psf.

$$D = a\frac{DT}{\sqrt{S}}$$

			Foundation Depths (D)		
Pole No.	Pole Class	DT	3’ Rd (a=50)	4’ Rd (a=43)	3’ Sq (a=41)
1	3700 lbs	8’	13’	11’	11’
2	5600 lbs	10’	16’	14’	13’
3	3700 lbs	8’	13’	11’	11’
4	4800 lbs	9’-6”	15’	13’	13’

Strain Pole and Foundation Selection Example

Figure 850-15

Conduit Sizing Table			
Trade Size	Inside Diam. (inches)	Maximum Fill (inch²)	
		26%	40%
1/2”	0.632	0.08	0.13
3/4”	0.836	0.14	0.22
1”	1.063	0.23	0.35
1 1/4”	1.394	0.40	0.61
1 1/2”	1.624	0.54	0.83
2”	2.083	0.89	1.36
2 1/2”	2.489	1.27	1.95
3”	3.09	1.95	3.00
3 1/2”	3.57	2.60	4.00
4”	4.05	3.35	5.15

Conductor Size Table			
Size (AWG)	Area (inch²)	Size (AWG)	Area (inch²)
# 14 USE	0.021	2cs (# 14)	0.090
# 12 USE	0.026	3cs (# 20)	0.070
# 10 USE	0.033	4cs (# 18)	0.060
# 8 USE	0.056	5c (# 14)	0.140
# 6 USE	0.073	7c (# 14)	0.170
# 4 USE	0.097	10c (# 14)	0.290
# 3 USE	0.113	6pcc (# 19)	0.320
# 2 USE	0.133		

Conduit and Conductor Sizes

Figure 850-16